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Hydrological trends and connections from catchment to lake in northern conditions

Thesis submitted in a partial fulfillment of the requirements for the degree of Master of Science in Technology.

In Espoo 15.12.2018
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Abstract of master's thesis

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Abstract

Lake Pesiöjärvi and its catchment form a middle-sized forested basin in eastern Finland with broad and long hydrological observations and datasets. This work utilised these datasets to study two separate entities. The first objective was to research trends in meteorological, hydrological and hydrochemical time series with Mann-Kendall trend and Sen's slope tests. The relation of the observed trends to changing climate and land use was also studied. For this purpose a land use analysis was made, which compared the past and present situation of land cover and forestry practices in the catchment. Second objective was study the role of groundwater flow in the water budget of the lake. The analysis was performed with a simple water budget calculation. Evaporation was estimated by correcting Class A pan measurements with coefficients derived with bulk aerodynamic method. The calculation utilised evaporation raft measurements from the lake. In addition, the sensitivity of the water budget analysis to the magnitude of evaporation was inspected by comparing two additional evaporation estimates.

The trend analysis revealed positive trends in winter and springtime mean discharge and annual and spring minimum discharge. In addition, precipitation and air temperature showed positive trends in early winter. Annual maximum observed snow water equivalent and lake ice break-up date exhibited negative trends. Total nitrogen concentration had positive trends in lake surface in summer and lake bottom in winter. An upstream Lake Pieni-Pesiöjärvi exhibited positive trend for total nitrogen in winter for the entire water pillar and negative trend in lake surface in spring. The land cover analysis revealed a decrease of 0-9 km^2 or 0-8 % of catchment area in peatland forest and similar increase in forest in mixed or mineral soil. The major transformer of land was estimated to be peatland drainage. The relatively small changes in the catchment land cover lead to the conclusion that the observed trends could be attributed to changing climate.

The annual average of groundwater inflow to lake was 27 000 m^3/d, which was 25 % of the net inflow (sum of all input and loss terms apart from the lake discharge). The flow rate against the area of the lake was 2,1 mm/d. The intra-annual variation of groundwater inflow was observed to follow variations in groundwater table elevation and lake water level. The variation of the percentual share of groundwater flow in the water budget was mostly governed by surface runoff and snowmelt. The used evaporation estimate had only minor effect on the annual average values of groundwater inflow, but was found to alter the intra-annual variation during summer and change the locations of the annual peak and low values.

Keywords catchment hydrology, trend analysis, climate change, land use, groundwater-surface water interaction, lake water budget, lake evaporation

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Tiivistelmä

Kainuussa sijaitsevalla Pesiöjärven valuma-alueella on suoritettu monipuolista hydrologista seurantaa 1980-luvulta asti. Tämän työn ensimmäisenä tavoitteena oli koota yhteen olemassa olevia aineistoja ja selvittää näkyykö alueen meteorologisissa, hydrologissa ja hydrokemiallissa havaintoaineistossa ajallisia muutoksia. Menetelminä käytettiin Mann-Kendallin trendi- ja Senin kulmakerrointestiä. Jotta mahdollisten muutosten syitä voitaisiin työssä arvioida, suoritettiin laaja maanpeite- ja maankäyttöanalyysi, missä verrattiin aikasarjojen alun ja nykyisen maanpeitteen ja maankäytön muutosta. Työn toisena tavoitteena oli arvioida pohjavesivalunnan osuutta Pesiöjärven vesitaseesta. Analyysin pohjana käytettiin yksinkertaista vesitase-analyysiä. Järvihaihduntaa arvioitiin korjaamalla astiahaihduntahavaintoja kertoimilla, jotka oli laskettu aerodynaamisella menetelmällä. Laskennassa hyödynnettiin Pesiöjärvellä käytössä olleen haihduntalautan havaintoaikasarjoja. Lisäksi vesitaseen herkkyyttä haihdunnan suuruuteen tutkittiin vertailemalla kahta vaihtoehtoista haihdunta-arviota.

Trendianalyysi paljasti nousevia trendejä talven ja kevään kuukausien keskivirtaamissa sekä vuosittaisten ja kevään jaksojen alivirtaamissa. Lisäksi sadanta ja ilman lämpötila osoittivat nousevia trendejä alkutalvesta. Talven suurimmat havaitut lumen vesiarvot ovat pienentyneet ja jäänlähtö on aikaistunut havaintojaksolla. Kokonaistypen konsentraatiossa havaittiin nouseva trendi pintavedessä kesällä ja pohjan lähettyvillä talvella. Osavaluma-alueella sijaitsevan Pieni-Pesiöjärven kokonaistypen konsentraatiossa havaittiin nouseva trendi vesipatsaan keskiarvossa talvella ja laskeva trendi pintavedessä keväällä. Maanpeiteanalyysissä havaittiin turvemaametsän pinta-alan pienentyneen 0-9 km^2, mikä on 0-8 % valuma-alueen pinta-alasta ja vastaavasti metsäisen seka- ja mineraalimaan alan kasvaneen. Merkittävin tekijä maanpeitteen muutoksessa oli turvemetsien ojitus. Suhteellisen pienet muutokset maanpeitteessä johtivat päätelmään, että havaitut trendit johtuvat ilmastotekijöistä.

Järveen tulevan pohjavesivalunnan vuosikeskiarvoksi saatiin 27 000 m^3/d, joka oli 25 % nettotulovirtaamasta (tulo- ja häviökomponenttien summa poisluettuna järven lähtövirtaama). Järven pinta-alaan suhteutetuksi valunnaksi saatiin 2,1 mm/d. Vuodensisäisen pohjavesivalunnan vaihtelun todettiin seuraavan pohjaveden ja järven vedenpintojen korkeuksien vaihteluita. Merkittävin tekijä pohjavesivalunnan prosentuaalisen osuuden vaihtelussa suhteessa vesitaseeseen oli pintavalunta. Käytetyllä haihdunta-arviolla oli vähäinen vaikutus pohjavesivalunnan vuosikeskiarvoon, mutta sen havaittiin vaikuttavan merkittävästi vuodensisäiseen vaihteluun ja muuttavan vuoden suurimman ja pienimmän arvon ajankohtia.

Avainsanat valuma-alueen hydrologia, trendianalyysi, ilmastonmuutos, maankäyttö, pohjavesi-pintavesi-vuorovaikutus, järven vesitase, järvihaihdunta

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Symbols

A_{gauged}	m^2	area of discharge gauged sub-catchments
$A_{cathment}$	m^2	area of Pesiöjärvi catchment excluding Lake Pesiöjärvi
A_{lake}	m^2	area of Lake Pesiöjärvi
C_l	-	correction coefficient for liquid precipitation
C_s	-	correction coefficient for solid precipitation
E	m^3/s	evaporation (water budget)
E_{lake}	mm/d	lake evaporation
$E_{Class\ A}$	mm/d	Class A pan evaporation
I	m^3/s	groundwater inflow to the lake
Q_{netin}	m^3/s	net flow of water to and from the lake excluding lake discharge
P	m^3/s	precipitation (water budget)
P_l	mm/d	liquid precipitation
P_{lp}	-	share of liquid precipitation from total precipitation
P_s	mm/d	solid precipitation
Q_{out}	m^3/s	lake discharge
$Q_{sub\text{-}catchment}$	m^3/s	runoff of upstream sub-catchment
R	m^3/s	surface runoff
RH	%	relative humidity
S_{lake}	m^3	lake water storage
T_a	^oC	air temperature
T_w	^oC	surface water temperature
W	m	lake water level
e_0	mb (0,1 kPa)	saturation vapour pressure at water surface
e_2	mb (0,1 kPa)	water vapour pressure 2 m above water surface
f_{month}	-	monthly correction coefficient for pan evaporation
k_{area}	-	area factor for surface runoff
t	d	time step
u	m/s	wind speed at 2 m above water surface
ΔS	m^3/s	change of lake water storage

Abbreviations

CLC	Corine Land Cover
EEA	European Environment Agency
FMI	Finnish Meteorological Institute
GTK	Geological Survey of Finland
GW	Groundwater
HBV	*Hydrologiska Byråns Vattenbalansavdelning* model
HQ	High discharge
LIVI	Finnish Transport Agency
LUKE	Natural Resources Institute Finland
MAVI	Agency for Rural Affairs
MK	Mann-Kendall trend test
MML	National Land Survey of Finland
MQ	Mean discharge
NQ	Low discharge
SNHT	Standard Normalised Homogeneity Test
SW	Surface water
SWE	Snow Water Equivalent
SYKE	Finnish Environment Institute
TN	Total nitrogen
VRK	Population Register Centre
WSFS	Watershed Simulation and Forecasting System
WMO	World Meteorological Organization

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1 Introduction

1.1 Pesiöjärvi northern research catchment

The lake Pesiöjärvi and its catchment form a middle-sized forested basin in eastern Finland near Suomussalmi Village. In late 1970s' the Pesiöjärvi catchment was chosen as a joint research site by the University of Oulu, the Hydrological Office of the National Board of Water in Finland, and the Kainuu Water Precinct. The aim was to study water and chemical budgets, the role of land use in the budgets, and the status of groundwater in the area. For this purpose, extensive field investigations were conducted and gauging stations of different hydrological parameters were installed in the catchment area.

Despite the extensive monitoring performed in the catchment, very few studies have been published from the Pesiöjärvi data. Postila (1981) studied the water balance of the catchment and summarised detailed land cover and use results, which provided an excellent description of the past situation of the catchment. Later Ahlberg et al. (1990) studied the variations in the quality of groundwater and surface water, Mäkinen and Soveri (1994) applied HBV-model in the catchment and Elo (1999) studied the correlation between lake water temperature and lake evaporation.

This work was motivated by the available broad and long observations and datasets of Pesiöjärvi catchment, and focused on two separate entities. First, the meteorological, hydrological and hydrochemical trends were researched and their relation to climate change and land use was studied. For this purpose a land cover and use analysis was also performed. Second, water budget analysis was performed to study the role of groundwater in the net inflow to Lake Pesiöjärvi. The water budget analysis included estimation of lake evaporation based on the bulk aerodynamic method, which utilised evaporation raft measurements from Lake Pesiöjärvi. The subsections below provide short introduction to the themes and Section 1.4 presents the goals of this thesis.

1.2 Hydrological and hydrochemical trends

1.2.1 Climate change and trend detection

Climate change is one of the most profound scientific issues of this century. According to IPCC (2018), globally climate change has been proven to for example increase mean temperatures of land and ocean surface, increase or decrease precipitation, strengthen extreme weather events and change climate patterns. Climate change can lead to alteration of the hydrological cycle, as well as regional and catchment scale hydrology and hydrochemistry. However some of these changes, like precipitation, can be very region-specific (Hartmann et al. 2013).

The climate change can be researched either by looking at the future development with climate models with appropriate climate projections or inspecting already occurred changes in observations of different climatological parameters. A well-established method of studying climate change impact is trend analysis of time series of different climate, hydrological and hydrochemical data (Helsel & Hirsch 2002; Kundzewicz & Robson 2004; Bayazit 2015). Trend analysis means researching whether a time series exhibit a significant positive or negative trend by the means of statistical tests. In the case of hydrological and hydrochemical quantities, trend analysis is the only way to ascertain climate change impacts, since even when climate models predict changes of temperature and precipitation, their effects on the rest of water cycle are complex and can only be hypothesised.

In Finland, the annual mean and especially spring temperatures have shown a positive trend as reported by Tuomenvirta (2004) and Jylhä et al. (2004). Jylhä et al. (2004) projected increased precipitation especially in winter months. Korhonen and Kuusisto (2010) studied trends in the discharge regime in Finland. They reported no significant change in annual mean discharge but instead a change in the intra-annual distribution of streamflow, with increased winter and spring discharges and annual low flow, and earlier spring high flow timing. These findings are in line with results around Baltic Sea basin (Käyhkö et al. 2015) and in Europe (Blöschl et al 2017). Käyhkö et al. (2015) related the earlier spring flood peak to earlier snowmelt and argued that change in temperature rather than precipitation explained better the changes discovered in the discharge. In addition they reported shorter ice cover season of water bodies. However, some of the reported trends varied within the borders of Finland, e.g. SWE values were observed to decrease in southern but increase in northern Finland (Hyvärinen 2003). The increased SWE in northern parts of Finland is most likely due to the air temperature remaining low enough to increase snowfall.

Climate change does not only affect hydrology, but also flow of substances within land and water systems. Especially the more common mild winters with increased heavy precipitation and runoff coupled with decrease in snow cover and frozen ground can increase soil erosion and leaching of nutrients (Koskiaho et al. 2010). Tattari et al. (2017) detected positive trends in total nitrogen and nitrate concentrations in both forested and agricultural areas in 1981-2010.

Climate change influence in hydrological cycle and discharge regime is complex and still somewhat poorly known, especially in future time scale. Studies inspecting the past climate change impact on hydrology in Finland have focused on national scale using the longest available time series. However, there is clear lack of studies on the change of hydrology in small individual catchments. The study of climate change influence in small catchments is interesting because their size makes it feasible to inspect other influencing factors, such as land cover and use, in more detail. In addition, knowledge of the climate change impact dependence on prevailing land cover type in a catchment can improve the accuracy of future projections.

1.2.2 Land cover influence on catchment hydrology

In order to assess the causes of trends in the catchment hydrology or hydrochemistry, knowledge about significant land cover changes and land use practices is required from time before and throughout the observation period. Possible land use changes or forestry practices that have been shown to affect catchment hydrology include e.g. deforestation and reforestation (Brown et al. 2012; Koivusalo et al. 2006), land drainage (Seuna 1981; Koivusalo & Laurén 2011), agricultural development (Schilling et al. 2008) and urbanization (Guan et al. 2015).

Land cover and use influence on catchment hydrological processes is an intricate and complex phenomenon. This becomes ever more important when the state of land cover is disturbed by anthropogenic activities. Because of the abundant amounts of forests and peatlands in Finland, research in Finland has for long focused on the hydrological and hydrochemical response to different forestry practices, such as loggings and drainage (Hyvärinen & Vehviläinen 1981; Seuna 1981; Starr & Päivänen 1981; Koivusalo et al. 2006; Koivusalo & Lauren 2011; Lepistö et al. 1995; Ahtiainen & Huttunen 1999; Nieminen et al. 2017; Nieminen et al. 2018). Research of the influence of land cover changes and forestry practices is important to better understand and manage e.g. surface water cycle and water management, surface water contamination and eutrophication.

Koivusalo and Laurén (2011) summarized the effects of different forestry practices, mainly loggings and peatland drainage, on hydrology in Finnish boreal forest environment. Logging operations, such as thinning and clear cutting, cause decrease in canopy interception, evapotranspiration and retention of water, and increase in discharge, accumulation of snow and intensity of snowmelt. Planting or natural growth of trees and other vegetation on the other hand have reverse effects, increasing interception and total evapotranspiration, hence decreasing discharge (Koivusalo et al. 2006). Loggings also increase nitrogen export to receiving water bodies (Kreutzweiser et al. 2008; Ahtiainen & Huttunen 1999) and can cause leaching of nitrate to groundwater (Luoranen et al. 2007). The long-term effects of loggings on nitrogen export are however varying, depending on e.g. the type and timing of the logging practice, site hydrology, weather patterns, soil properties and rate of vegetation recovery (Kreutzweiser et al. 2008).

Drainage can have varying and sometimes contradictory effects on hydrology and hydrochemistry depending on the soil and hydrological qualities of the catchment and length of time scale. Koivusalo and Laurén (2011) noted that drainage increased hydrological activity and opened new pathways for groundwater seepage, while Seuna (1981), Sirin et al. (1991) and Beheim (2006) reported decrease in water retention and increase in discharge from drained catchment in the first years after drainage. Increased flood peaks and low flows were reported by e.g. Sirin et al. (1991), Seuna (1981), (Prévost et al. 1999) and Beheim (2006). Hyvärinen and Vehviläinen (1981) pointed out increased spring and summer high flows. Increase in nutrient, especially nitrogen, export can be expected initially after drainage operations (Lepistö et al. 1995; Ahtiainen & Huttunen 1999; Nieminen et al. 2017). Drainage induced drop in water table causes mineralisation of peat due to increased aeration and subsequent microbial activity (Nieminen et al. 2017).

The long-term changes caused by drainage depend on the presence and growth of vegetation, especially trees, in the drained area (Koivusalo & Laurén 2011; Starr & Päivänen 1981; Sirin et al. 1991). If reforestation occurs, runoff starts to decrease. The reasons for this are increased canopy interception and evapotranspiration by tree stands (Koivusalo & Laurén 2011) and decrease of snow accumulation and melting intensity, the decrease of drainage efficiency and the exhausting of water stored in the peat (Seuna 1981). Starr and Päivänen (1981) found that after a long period of time, discharge from drained peatland can fall below that of similar pristine areas. The long-term influence of drainage on discharged nutrients has not shown significant increase within 20-30 years from the drainage (Prévost et al.1999; Ahtiainen & Huttunen 1999), but Nieminen et. al (2017) reported over doubled total nitrogen and phosphorous concentrations from catchments drained roughly 60 years ago compared to areas drained 20-30 years ago.

According to Nieminen et al. (2018), ditch network maintenance in peatland forest has only minor impact on catchment runoff or dissolved nitrogen or phosphorous export compared to similar virgin areas, although Koivusalo and Laurén (2011) mention that increased impact can be expected when the depth or width of the ditches are increased. However, limited research is available on the particulate nutrient export after the ditch network maintenance compared to dissolved nutrients (Nieminen et al. 2018). Particulate nutrient export is argued by Nieminen et al. (2017) to possibly be a considerable chronic nutrient export method especially from old drained peatland areas that are subjected to ditch network maintenance.

Fertilisation of peatland forest is conducted to facilitate tree growth in logged and/or drained areas. Fertilisation is usually executed concurrently with logging or ditch network maintenance operations. Fertilisation does not have any direct influence on hydrology, but it can cause increased export of nutrients initially after the operation. According to Nieminen and Ahti (2000), nitrogen fertilisation with urea does not increase nitrogen leaching from peatland forest unless done during winter. Kenttämies (2006) reported that fertilisation induced nitrogen export has diminished significantly from 1977 to 1993 due to improved planning and use of new slowly dissolving fertilisers.

Because of the varying and intricate impacts of land use on catchment hydrology and hydrochemistry, the study of land cover and use is prerequisite for successful trend analysis study. However, trend analysis studies have often considered this in only rough scale, because of limited availability of land cover data from the past and large areas and great workload involved. By including a land use analysis to the trend analysis it is possible to better explain or neglect causes for observed trends. In addition, information of existing trends in combination with knowledge of prevailing catchment land cover can improve knowledge on management of water resources and future projections.

1.3 Water budget and groundwater

1.3.1 Role of groundwater inflow in lake water budget

Groundwater (GW) as a component in surface water (SW) management has received increasing attention in the recent decades (Rosenberry et al. 2015; Fleckenstein et al. 2010). This is due to growing awareness of the importance of groundwater to many hydrological, biogeochemical and ecological systems as well as the inclusion of more holistic management of water resources in new legislation such as the EU Water Framework directive (Fleckenstein et al. 2010). This has led to emerging multidisciplinary approaches to management of GW-SW interaction.

GW-SW interaction is complex and dependent on many factors in the surroundings and in the GW-SW interface, such as climate, geology and hydrogeology, and different biochemical processes (Fleckenstein et al. 2010; Sophocleous 2002). GW is not only an important part in the present condition of water resources but it can act as a persistent source of pollution or nutrient loads due to the long water and chemical retention time of aquifers (Nakayama & Watanabe 2008; Rosenberry et al. 2015).

GW-SW interaction can be studied by modelling and measurements or combination of both. According to Kalbus et al. (2006), the measurement methods can be categorised into direct measurement of flow, heat tracer methods, methods applying the Darcy's law and mass balance approaches. The mass balance method can utilise either chemical tracers or catchment water budget. Calculating the amount of GW inflow to a surface water body (e.g. lake) with water budget requires knowledge of lake evaporation. Different model types for GW-SW interaction include e.g. two-dimensional finite element model or GW flow model, which is sometimes integrated with surface flow model (Rosenberry et al. 2015; Ala-aho et al. 2017). Measuring methods and models for GW studies often suffer from the uncertainties caused by geological and temporal heterogeneities and the choice of scale (Kalbus et al 2006). A suitable method can be chosen based on the aim of the study, desired resolution, available data, resources available for sampling and studied time scale.

In the context of lake water budget, the GW-SW interaction affects the water budget in two ways: aquifers can retain precipitation as groundwater that percolates through the soil, or release groundwater from the aquifers to either on ground (springs) or straight to the lake. Water can also flow from the lake to groundwater aquifer in suitable conditions. The role of groundwater in catchment and lake water and nutrient budgets can be significant, but the magnitude of the influence is difficult to estimate. Rosenberry et al. (2015) have reviewed and summarised over 100 studies of GW-lake interaction, containing cases of GW flow to lake and vice versa. In most cases the flow was from GW to lake. The median value of GW inflow to lake in the study is 25 % of all input and loss terms, but the results of the different studies varied significantly, from almost 0 to 94 % share of GW inflow from input terms. The importance of GW inflow in lake water budget also decreases with increasing area of lake starting from 100 ha up. For lakes of the size of Lake Pesiöjärvi the interpolated share of GW inflow from lake water budget is around 15-20 %.

GW-SW interaction is dependant of the surrounding soil type, but the role of soil type in GW flow from one soil type to another or to lake is yet poorly understood. In Finnish context the most important soil formations and types are eskers and peatland. Esker aquifer interaction with surface waters was studied by e.g. Ala-aho et al. (2013) and Rossi et al. (2012). GW flow dynamics in peatland surrounded water systems have been studied less, but Ala-aho et al. (2017) found that groundwater can be a significant factor in runoff generation in peatland surrounded riparian areas, especially in the generation of surface runoff during drier periods. However, the variation in groundwater exfiltration through peat soil is high and can vary between sub-catchments with different properties or e.g. drainage situations (Rossi et al. 2012).

Even though groundwater is an important component in lake water and nutrient budgets, GW inflow quantification is difficult and often ignored in the study of surface water budgets and nutrient loading. According to Rosenberry et al. (2015), the reasons for this are e.g. the invisibility of GW, the requirement for multiple approaches for acquiring temporally and spatially accurate results, the inaccessibility of GW-SW interface and the lack of suitable quantification methods. Since Pesiöjärvi catchment has an extensive history of hydrological monitoring in the quantities crucial to water budget, it poses a promising opportunity in the study of the role of GW flow in the water budget of a forested, relatively pristine lake. By comparing the results from similar areas with different sizes, soil types and properties, it would be possible to achieve general knowledge of how large influence groundwater has for certain types of lake systems. This kind of database could be used to further improve holistic water management and research of GW-SW interaction.

1.3.2 Estimation of evaporation

Evaporation is a major physical quantity in the water budget analysis in addition to precipitation and runoff. Evaporation is difficult to estimate because it varies depending on whether evaporation occurs from water surface, soil or plants (transpiration and interception). The meteorological quantities governing evaporation are e.g. short- and long-wave radiation, air temperature and evaporating surface, difference in relative humidity of air on the surface and above, and wind speed.

Often evaporation is the missing component in the water budget and the water budget analysis is the simplest method to estimate evaporation at least for short rainless time periods. This method has its weaknesses, since often at least groundwater flow is unknown as well. However, if evaporation can be estimated, it is possible to quantify the groundwater flow in and out of the lake (Virta 1981; Rosenberry et al. 2015). The sensitivity of the water budget components to the used evaporation estimation has clear lack of research especially when groundwater is included in the analysis.

In the past, evaporation has been commonly measured with evaporation pans, in Finland mostly with the Class A pan (Sjöblom 2013a), although the USSR origin GGI-3000 pan has been used as well especially on floating rafts. The problem with pan evaporation is that as such the pan value does not represent evaporation occurring in natural environment and thus needs to be corrected to be of use in the estimation of e.g. lake or soil evaporation or areal evapotranspiration (Kajander 1973; Finch & Calver 2008). Evaporation can also be estimated by methods utilizing energy balance, like with the standard Bowen ratio energy balance (Majidi et al. 2015) or aerodynamic factors and surface resistance (Peel & McMahon 2014). A popular method for estimating potential evapotranspiration is the Penman-Monteith equation. However according to Winter et al. (1995) these methods can have varying accuracy in climates different from where they were created, and are not necessarily representative of lake evaporation. In addition, most of these methods require many input variables, although emerging remote sensed data can enable broader use of these methods globally (Liou & Kar 2014).

In 1970s' and 1980s' in Finland extensive lake evaporation studies were conducted utilizing a somewhat less common bulk aerodynamic method, which is based on mass transfer (Järvinen 1978; Järvinen & Huttula 1982; Tuominen & Järvinen 1973; Virta 1981). The method is derived from theoretical assumptions, mainly Dalton's formula (Järvinen 1978). The unpopularity of the bulk aerodynamic method is due to the requirement of extensive meteorological and hydrological measurements from the study site performed on a raft or fixed weather station on top of the lake. However the method has the benefit of acquiring better estimation of the daily fluctuation of evaporation. In addition, Tuominen and Järvinen (1973) describe it as being feasible method for short observation periods, when evaporation amounts are small and when estimating evaporation near thaw and freezing period.

The bulk aerodynamic method was used in this study to calculate suitable monthly correction coefficients for the Class A pan evaporation. This enabled the acquisition of more accurate estimate of lake evaporation over the evaporation period. Because the coefficients are calculated monthly instead of constant coefficient for the whole evaporation period, it provides more accurate information of the difference in Class A pan evaporation and lake evaporation throughout the summer months. The motivation for the utilisation of the bulk aerodynamical method for evaporation derives from the history of intense evaporation studies performed in Pesiöjärvi catchment with evaporation raft and pans.

1.4 Objectives

The first objective of this work was to study by means of trend analysis if there are trends present in meteorological, hydrological and hydrochemical variables in Pesiöjärvi catchment and if they comply with previously observed trends in Finland. In addition, the aim was to explore the role of climate change and land use in the trends present. For this purpose a detailed land cover and land use analysis of past and present was performed. However, analysis of the influence of any specific land change practice on the catchment hydrology was omitted from the study due to lacking data of the timing of such occurrences.

The aim of the land cover and use analysis was to detect and quantify possible large changes in land cover and use over the research period, in order to identify or neglect causes for possible observed trends in the catchment hydrology. If land use was to be deemed negligible, all the observed trends could be attributed to climate change. In hydrochemistry, the focus in the land use analysis was in causes of nitrogen leaching, since due to changes in sampling and laboratory procedures, there exist no heterogeneous time series of phosphorous concentration from the catchment.

In the context of GW-SW interaction between lake and catchment, the goal was to prove that with a simple lake water budget analysis it is possible to acquire an adequate estimate of the role of GW flow in a mid-sized lake system. The result, if used in combination with similar studies for different types and sizes of catchments, can help to regulate and plan holistic water management and better understand the chemical and nutrient loads to surface waters.

For the water budget, lake evaporation was calculated with bulk aerodynamic method utilising the extensive evaporation raft and Class A evaporation pan data from the Pesiöjärvi catchment. The attempt was to view if the evaporation raft data was of adequate quality for the water budget analysis. The sensitivity of the lake water budget to the used evaporation estimate was also studied by comparing three different evaporation estimates.

2 Site description and data

2.1 Description of the catchment

Pesiöjärvi catchment is situated in eastern mid-Finland, near Suomussalmi Village (Figure 2.1). The catchment belongs to the Oulujoki watershed and is located at the latitude of 64.95 N. The catchment altitude in N2000 ranges from 214 to 300 m from sea level. The size of Pesiöjärvi catchment is 103 km^2 and lake percentage is 17 %. The size of Lake Pesiöjärvi is 13 km^2, its mean depth is 4 m and the maximum depth is 14 m. The catchment area (Figure 2.2) consists of 75 % forested area, of which around 60 % is boreal forest and rest spruce or pine dominated peatland forest. 5 % of the area is open peat bogs. The share of rural and urban area is low, under 4 % together. The main soil types in the area are sandy till and peat. A detailed specification of the land cover in Pesiöjärvi catchment can be found in Appendix 3. (Postila 1981; SYKE 2014, Hertta –Environmental database)

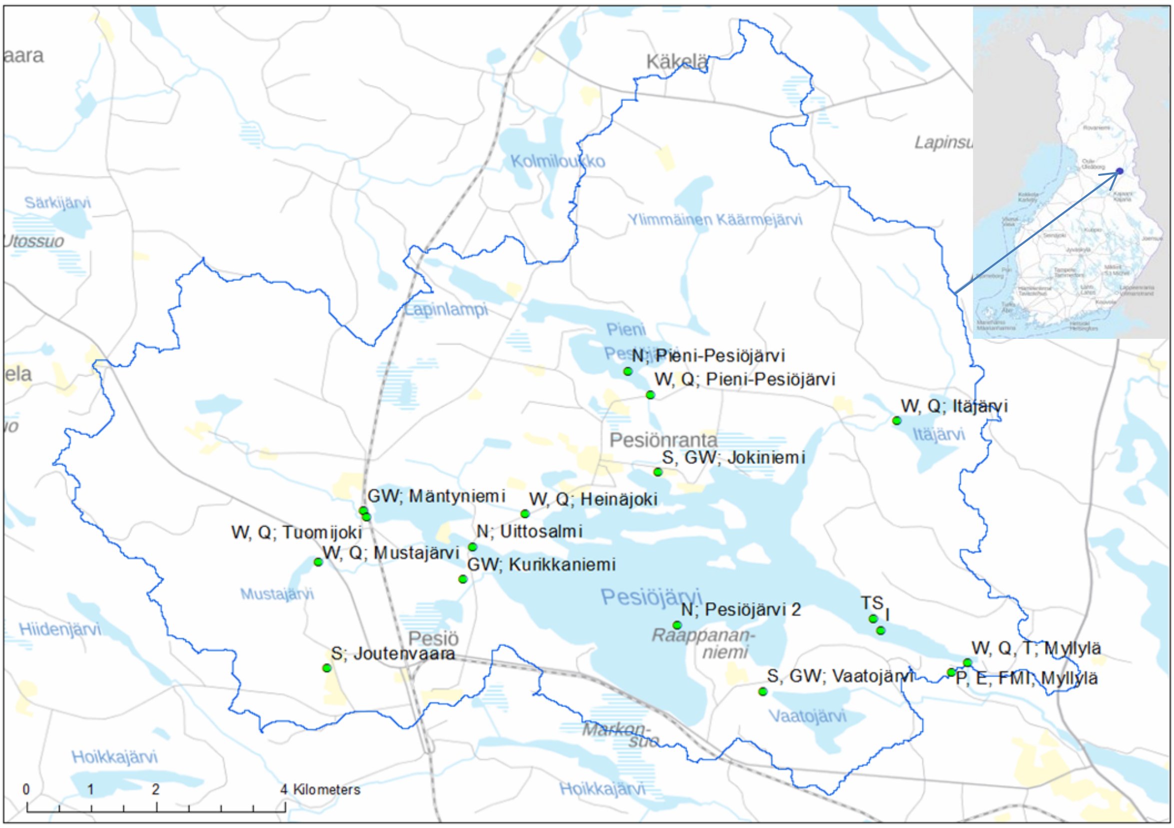

Figure 2.1 The location of Pesiöjärvi catchment in Finland and the locations of observation sites of meteorological, hydrological and hydrochemical quantities in Pesiöjärvi catchment. The labels express E: Class A pan evaporation, FMI: Finnish Meteorological Institute weather station, GW: groundwater station, I: lake ice thickness, N: nitrogen sample point, P: precipitation, Q: discharge, S: snow course, T: water surface temperature, TS: water temperature probing, W: water level.

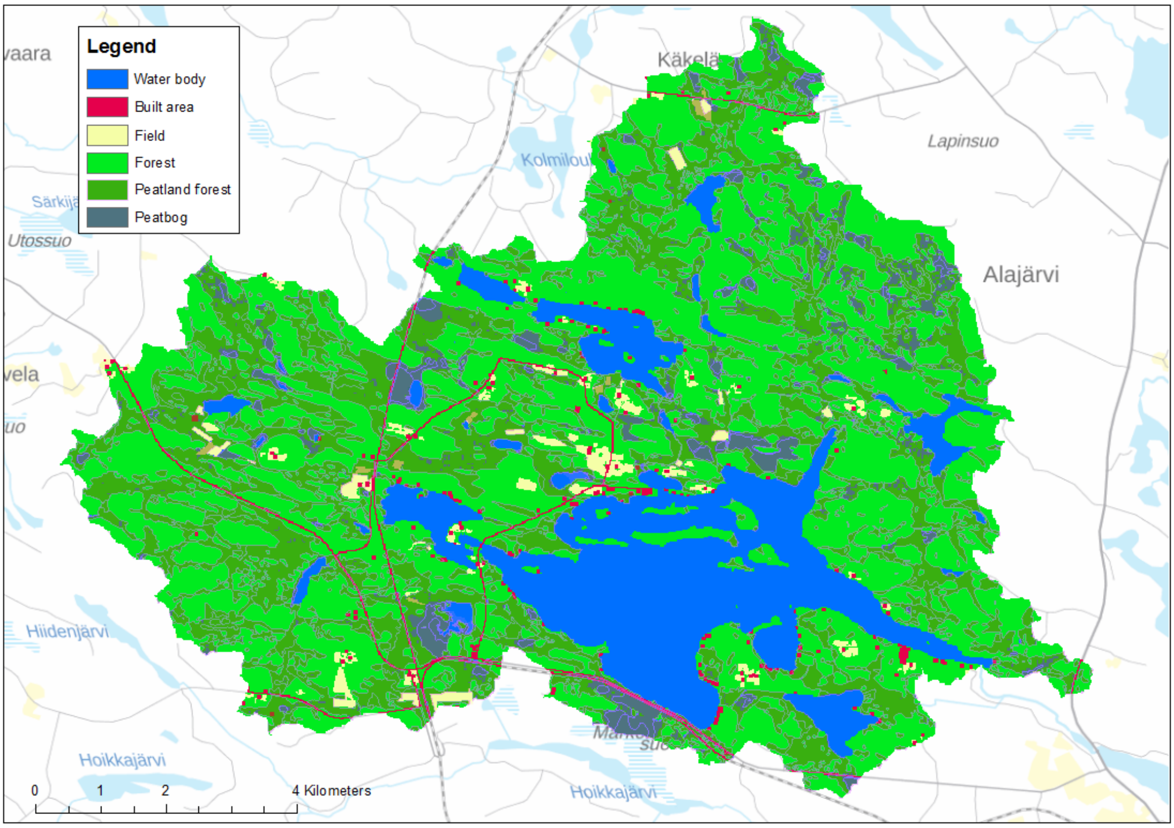

Figure 2.2 The land cover distribution of Pesiöjärvi catchment.

Calculated for the time period of 1980-2017, annually Pesiöjärvi catchment receives on average 690 mm of gauged precipitation. Of this 420 mm leaves as runoff and about 270 mm is evaporated or recharged as groundwater or otherwise lost. The intra-annual variation in discharge is strong and common to a Finnish catchment. Winter and early spring discharge is low, with annual minimum flow values occurring on average in April. In May-June discharge increases rapidly to annual maximum level due to snow melt. Spring flood period is followed by a gradual decrease of discharge through the summer until autumn precipitation increases runoff again. Occasionally annual high and low flows can occur also in autumn. The lake ice cover as well as land snow cover period in the catchment is about six months.

2.2 Land cover and use data

Detailed field investigations (including land cover, the density and type of forest, canopy cover and soil type) in the area were carried out in fall and winter 1979-1980 (Postila 1981). The results were listed as percentage of the catchment area and included the whole catchment, and several sub-catchments. For forestry practices, Postila (1981) included information of logged boreal forest area in 1980 as well as planned loggings in government owned land in 1980-1985. Detailed amounts of fertilizers used in the catchment area (field and forest) in summer 1979 and lists of drainage projects were reported. Supporting information of known fertilising projects in forested peatland and mineral soil areas throughout 1970s' and -80s', as well as virgin and drainage network maintenance operations were provided in the archived maps of SYKE.

For estimation of the present situation of land cover and forestry practices, Corine Land Cover (CLC) data from 2012 (SYKE 2014) was used, with additional information retrieved from GIS-layers of swamp areas (SYKE 2011), drained peatland areas (MML 2017), and surface soil type (GTK 2009). Up-to-date information about loggings and fertilising is not available and therefore the analysis required the assumptions described in Section 4.2.2.

2.3 Hydrological and meteorological measurements

2.3.1 Water level

Water level in Lake Pesiöjärvi has been measured since 13 June 1979 until present. The gauging station identification number in Hertta environmental database of SYKE is 5900180. From the beginning of the records to the 27 August 2014 the gauging device was a limnigraph, which recorded mechanically the level of a flute floating in a well and drew the values on paper (Sjöblom 2013c) (Postila, 1981). In 2014 the site was automated with OTT pressure transducer and data logger. The water level gauge location is shown in Figure 2.1.

The method by which the water level value was recorded into the database affected the quality of the data. In Lake Pesiöjärvi before year 1986 the daily water level value recorded was water level value at 8:00, and after 1986 the daily mean water level was calculated from either the limnigraph paper or automatic recordings. The former method had the possible weakness of losing some fast occurring HQ situations, which occurred during the day and evening, but returned to normal level by the morning when the measurement was made, although in a lake this effect is not as prominent as in a river gauging station (Koskela, pers. comm. 2018).

Water level was also measured in several other sites around Pesiöjärvi catchment, which included most of the upstream lakes as well as two lakeless streams flowing to Lake Pesiöjärvi. Of these the lakes Mustajärvi (station id: 5900184), Pieni-Pesiöjärvi (station id: 5900183) and Itäjärvi (station id: 5900182) and the streams Heinäjoki (station id: 5900189) and Tuomijoki (station id: 5900188) were included in the water budget analysis. The measurements in these upstream sites were conducted from 1980 to early 1990s' with staff gauges that were read once a month (Moilanen & Känsäkangas, 1980) and changed to pressure gauges with Teloq logging devices before 1993 for daily recording (Soveri & Mäkinen 1993). Based on the measurements in the database of the Finnish Environment Institute the upstream lakes and rivers have had daily recordings sporadically through the 1990s' until August 2005, after which the measurements at the sites were terminated.

During the recording history there were only sporadic time periods during which there existed daily water level measurements from all of the gauged upstream lakes and rivers. The longest and most complete periods that were chosen to calculate the daily interval water budget are listed in Table 2.1. Figure 2.3 shows the number of measurement days per calendar month.

Table 2.1 The time periods when the Pesiöjärvi upstream sub-catchments have been gauged for daily water level and discharge.

Start day	End day	Duration (d)
10 Nov 1993	1 Jan 1994	52
2 Feb 1994	12 Jul 1994	160
8 Nov 1994	19 Dec 1995	406
1 Jan 1996	25 May 1996	145
12 Jun 1997	5 Nov 1997	146
17 Oct 2000	31 Aug 2001	318
20 Apr 2002	29 Jul 2002	100
Sum of days		1327

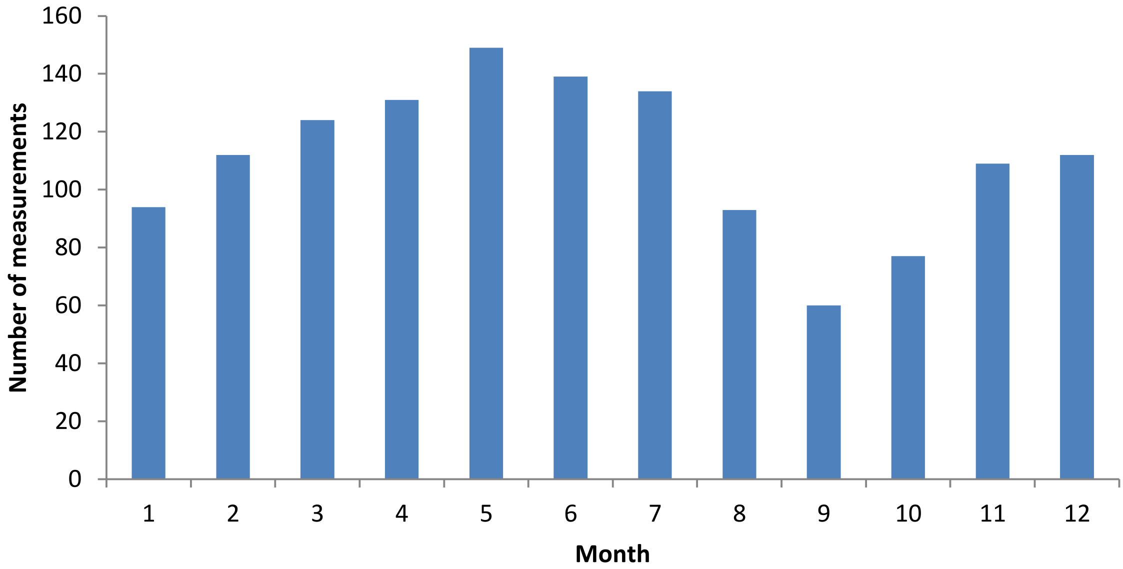

Figure 2.3 Number of days with water level and discharge gauging in the Pesiöjärvi upstream sub-catchments.

2.3.2 Discharge and runoff

In Lake Pesiöjärvi and the upstream lakes and rivers, discharge was estimated from the rating curves, which define the relationship between the lake or river water level and discharge based on the discharge measurements of the channel during known water levels (Korhonen 2007). The rating curve of lakes Pesiöjärvi, Mustajärvi, Pieni-Pesiöjärvi and Itäjärvi and streams Heinäjoki and Tuomijoki are available in the SYKE environmental database Hertta and the measuring locations are shown in Figure 2.1. The rating curve of Lake Pesiöjärvi is shown in Figure 2.4. For Lake Pesiöjärvi there exist two separate rating curves since the outlet point of the lake was renovated in summer 2011 by elevating the bottom of the discharge point. The lower rating curve was used to estimate discharge levels until 31 August 2011, after which the upper curve has been in use.

As Figure 2.4 shows, the new rating curve does not fall in line perfectly with the measurements in low flow (NQ) situations. The two measurements with the lowest water level yield on average 20 % smaller discharge than the rating curve suggests. The discharge time-series also exhibited a visible upward step around early 2010s'. This casts doubt on the reliability of the NQ values after 2011. Discharge from Lake Pesiöjärvi was visually compared with discharge from Lake Vellijärvi (station id: 5900160), which has catchment area of 139 km^2 and is situated 25 km north of Lake Pesiöjärvi. Lake Vellijärvi exhibited similar, but not as evident, positive step around the same time as Lake Pesiöjärvi, which implied that the step was due to some external reason and not caused by the alteration of the discharge point and the change of the rating curve.

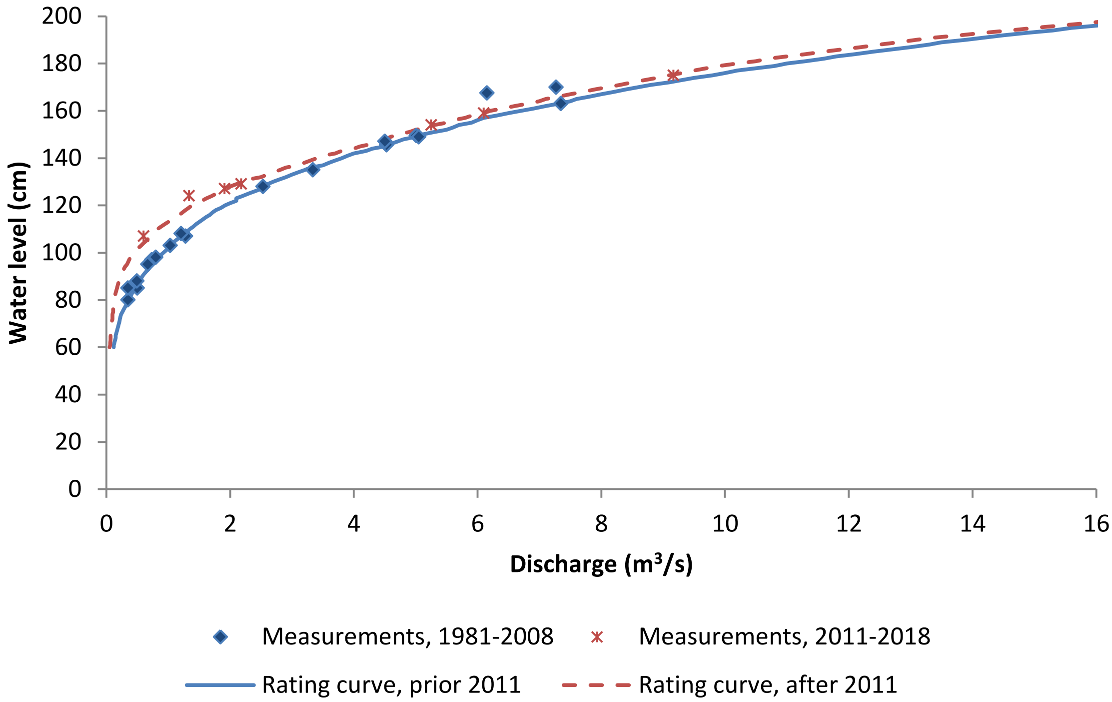

Figure 2.4 Rating curves of Lake Pesiöjärvi discharge point and the discharge measurements used to plot the curves. Two curves exist due to renovation of lake discharge point in 2011. The blue curve was used prior and red dashed curve after the renovation in 2011.

2.3.3 Evaporation

In Lake Pesiöjärvi daily Class A pan evaporation measurements were conducted every summer since 1981. Originally there were two pans, one standard Class A pan standing on ground and one Class A pan immersed in the ground with the aim to better reflect ground evaporation. The immersed Class A pan was terminated in 2006. The measurement site was located near the outlet of Lake Pesiöjärvi (Figure 2.1). According to Sjöblom (2013a) Class A pan is one of the standard evaporation pans approved by WMO and used globally. Its benefits are simplicity, cost and ease of management. Daily evaporation is calculated as the difference in water level fluctuation from previous measurement and precipitation measured beside the pan. In Pesiöjärvi catchment the evaporation measurement period starts in May-June and ends in September-October depending on the year.

In addition to the pan evaporation, there was an evaporation raft on Lake Pesiöjärvi during the summer months (June-October) between 1982 and 2000. The raft was measuring in 30 minute intervals the meteorological quantities that are needed to estimate lake evaporation with the bulk aerodynamic method: surface water and air temperature, wind speed at the height of 2 m above the water surface and relative humidity. More information on the layout of the evaporation rafts, as well as different aerodynamic equations for the estimation of lake evaporation is described in Järvinen (1978) and Järvinen & Huttula (1982).

Throughout its operation, the evaporation raft had issues with malfunctioning of sensors and data logging. The quality of the data was previously inspected by Elo (1999) and the best measurement series according to the report are shown in Table 2.2. The time series from summer 1983 were not used in this work due to the poor quality of the RH measurements. In 1987 there were some RH measurements above 100 %, which were forced to the value of 100 %.

Table 2.2 The most reliable measurement series of the evaporation raft according to Elo (1999). The data from year 1983 (in red) was not used in this work because of the inadequate quality of the relative humidity observations.

Year	Period	Wind speed	Air temperature	Relative humidity	Water temperature
1983	24 May – 15 Jun.	x	x		x
1987	5 Jun. – 12 Oct.	x	x	x	x
1991	15 June – 19 Sep.	x	x	x	x
1992	3 Jun. – 17 Jul.	x	x	x	x
1993	2 Jun. – 28 Aug.	x	x	x	x

2.3.4 Precipitation

Precipitation was measured with a rain gauge in FMI weather station located on the shore of Lake Pesiöjärvi (Figure 2.1) from the beginning of 1981. During the gauging period there were some 1-3 month-long periods with no precipitation data. These gaps were filled with measurements form a nearby Suomussalmi Village rain gauge, which was in the distance of 12 km towards east by southeast. Like the Lake Pesiöjärvi rain gauge, the Suomusalmi Village gauge was situated close to a lake and it had 2 m lower elevation from sea level. The measurements were available as daily precipitation accumulations starting from 8:00.

The precipitation gauge in Pesiöjärvi catchment was type Wild until 19 October 1981, after which it was changed to Tretyakov gauge (Taskinen & Söderholm 2016). The Tretyakov gauge was improved with new splintered wind shield (H&H modified Tretyakov) (Taskinen & Söderholm 2016) in 1 January 1992. In 12 December 2007 the gauging station was automated and the modified Tretyakov was replaced with the Vaisala VRG gauge (Taskinen & Söderholm 2016; Turtiainen et al. 2006), which was later replaced with OTT Pluvio (OTT Hydromet 2017) in summer 2013. Information of the changes in rain gauge type was retrieved from the SYKE hydrological model (WSFS) (Vehviläinen & Huttunen, 2001; SYKE 2018) metadata (Söderholm pers. comm. 2018).

Due to the use of different gauges there may exist heterogeneity in the precipitation time series. For example, Wild gauge loses considerably more snowfall than the other gauges (Söderholm 2018, pers. comm.). In addition to the gauge type induced heterogeneity, the accuracy of precipitation gauges depended on many other parameters such as state of precipitation (liquid or solid), elevation, evaporation, intensity of precipitation and wind condition at the gauge during rainfall events (Taskinen & Söderholm 2016; Vehviläinen 1992). According to Vehviläinen (1992) the correction factors for gauge measurements range from 2-12 % for liquid and 10-50 % for solid precipitation.

To account for heterogeneity, precipitation has to be corrected to better resemble the actual situation. Initially, the precipitation measurements were corrected by constant factors to consider differences in the efficiency of the gauges. The correction factors for different gauges are shown in Table 2.3 for liquid and solid precipitation separately. For climatic and aerodynamic corrections two different methods were used. The first method was to simply correct both liquid and solid precipitation separately with a constant factor. The used constants were 1,06 for liquid and 1,35 for solid precipitation, as suggested by Stenberg (2007). The second method corrected liquid and solid precipitation with the annual mean correction factors used in the WSFS model (Vehviläinen & Huttunen, 2001; SYKE 2018). The model firstly estimated the correction demand caused by wind based on the wind direction and speed from the three closest stations and the correction demand based on the state of precipitation. Secondly, the model compared the precipitation to discharge measurements from the catchment and corrected the precipitation gauge measurement to cover for the lack or surplus of water (Vehviläinen & Huttunen 2001; Söderholm, pers. comm. 2018).

To estimate the shares of liquid and solid precipitation, a relationship between air temperature and relative humidity called Koistinen's equation (Koistinen et al. 2004) was used. The equation estimates the probability of rain as

$$P_{lp} = \frac{1}{1 + e^{(22-2,7T-0,20RH)}}, \tag{2.1}$$

where P_{lp} is the share of liquid precipitation, T in degrees Celcius is air temperature and RH in percent is relative humidity. In line with Taskinen and Söderholm (2016), if $P_{lp} < 0,2$, precipitation was assumed as solid and if $P_{lp} > 0,8$, precipitation was completely liquid. In the case P_{lp} is between 0,2 and 0,8, precipitation was sleet consisting of P_{lp} share of liquid and 1- P_{lp} share of solid precipitation.

Air temperature and RH measurements were retrieved from FMI weather stations. The measurements were from Suomussalmi Village weather station until November 2000, after which the station was transferred to Myllylä by the shore of Pesiöjärvi next to the rain gauge (Figure 2.1). The RH time series had some gaps that were fixed with the monthly mean of the full time series.

Table 2.3 Gauge corrections for different precipitation gauges (Söderholm pers.comm. 2018).

Gauge information		Gauge correction	
Gauge type	**Last date of use**	**Liquid P**	**Solid P**
Wild	➔ 19th Oct. 1981	1	1
Tretyakov	➔ 1st Jan. 1992	1	0,98
H&H mod. Tretyakov	➔ 12th Dec. 2007	1	1,01
Vaisala	➔ Summer 2013	1	1,01
OTT Pluvio	➔ Present	1	1,01

2.3.5 Water temperature

The water temperature of Lake Pesiöjärvi has been observed as vertical temperature distribution three times a month since June 1985. The interval of the vertical distribution measurements was 1 m from surface to the depth of 13 m. The vertical temperature distribution measuring site is shown in Figure 2.1. In addition, daily surface water temperature has been measured in Lake Pesiöjärvi during open water season since June 2000. The measuring site for surface water temperature was close to the water level gauge (Figure 2.1).

In the trend analysis, this work utilised the water temperature time series from the vertical distribution. The time series was compiled from the seasonal surface temperature measurements. The seasonal time series were calculated from monthly average temperatures. During the observation period there were some months with no data, especially in 1985-86 and 1996. However, apart from two winter seasons and one spring season, there were at least two out of three months with temperature measurements in each season of each year. In case a season had one or more months without temperature measurements, an average of the months with temperature measurements was used in the time series.

2.3.6 Snow water equivalent

Snow water equivalent (SWE) is the measure of accumulated water in the snowpack. In Finland the field measurements of local SWE have been measured with so called snow course measurements (Sjöblom 2013b; Moisander 2014). One snow course measurement consists of 80 depth and 8 density measurements. The locations of the separate measurements are divided by terrain so that they represent the surrounding land cover conditions well. During snow cover season the measurements are done 1-2 times a month.

In addition, SYKE has developed a SWE simulation model that estimates SWE for the days between the snow line measurements. The degree-day grid point model calculates SWE based on the daily mean air temperature and precipitation and corrects the calculated values based on the snow line measurements (Sjöblom, pers. comm. 2018). The model has been used from 1990 onwards (Sjöblom 2013b), but it had some rearrangements in the code and parameters in 2003, 2004 and 2014 that may have caused some heterogeneity in the time series (Sirviö, pers. comm. 2018). In 2013 the land cover based weighting system was changed and in the subsequent process the model broke down and therefore there were no SWE model results available in SYKE database after 2013.

SWE was measured in Pesiöjärvi catchment in three different snow courses, Joutenvaara, Jokiniemi and Vaatojärvi (Figure 2.1) since 1980, but only Joutenvaara was still active until 2018. During the study period there were gaps of over a year in the data. According to Sjöblom (2013b) the snow course measurements were not entirely homogenous due to possible changes in the location and observers of the snow course measurements, which affected SWE model results as well.

2.3.7 Groundwater

In Pesiöjärvi catchment there are four groundwater gauging stations situated in different sides of Lake Pesiöjärvi (Figure 2.1). The stations Kurikkaniemi, Mäntyniemi and Vaatojärvi were founded on 1 November 1979 and Jokiniemi on 31 May 1981. Water table elevation data was available from all the stations in Syke POVET database throughout the operation period.

The monitoring of groundwater table in Pesiöjärvi catchment was carried out with standardised groundwater stations across Finland (Orvomaa & Mäkinen 2015). All stations included ten observation wells from which water table elevation was measured. A field average water table elevation was calculated from the well measurements. The gauging interval was twice a month. One of the observation wells also included a limnigraph that recorded daily water table elevation. In addition, water quality was monitored from groundwater samples taken from an observation well 2-4 times a year. (Soveri et al. 2001; Orvomaa & Mäkinen 2015)

2.3.8 Lake ice cover

Ice thickness measurements in Lake Pesiöjärvi were started in autumn 1999. The measurements were done three times a month throughout winter. The observation site is shown in Figure 2.1. Observations of lake freezing and thawing dates have been made since winter 1992-1993. The freeze and thaw dates were done by visual estimation by an observer from the shore of the lake (Korhonen 2015). The estimation was divided into four stages. For freezing the stages were "freezing of the shores", "freezing of the bays", "freezing of the lake within sight" and "freezing of the whole lake", and for thawing "thawing of the shores", "thaw areas out of the shore", "ice in movement" and "no ice within sight" (Korhonen 2015).

The lake freeze and thaw date time series had some gaps in the annual time series. Especially the freezing time series had a gap of 6 years in 2003-2008. However, the thaw date time series was relatively complete, with only two 1-year gaps present after 1996. However, heterogeneity may occur in the time series because of the nature of the observation of lake freeze and thaw dates.

2.3.9 Nitrogen concentration

Total nitrogen (TN), nitrate as nitrogen and ammonium as nitrogen were measured from water samples in different surface water bodies in Pesiöjärvi catchment. The earliest samples were from 1979 (Uittosalmi), but most sampling locations were started in the 1980s'. The samples were in general taken from 2-4 different depths 1-5 times a year with interval of 1-4 years, although some seasonal time series especially in winter and autumn had gaps up to ten years. The sampling locations with the longest and most complete time series for total nitrogen concentration were Pesiöjärvi 2 and Uittosalmi in Lake Pesiöjärvi and Lake Pieni-Pesiöjärvi (Figure 2.1). The time series are shown in Table 2.4.

The samples have been analysed in accredited laboratories of SYKE and Regional Centers. The laboratory analyses of total nitrogen were done according to the global standards and the method was described in Tattari et al. (2017) as follows: the TN was digested with peroxodisulphate and determined with a spectrometer.

Table 2.4 The most complete total nitrogen concentration time series for different seasons and water depths. The time series marked with (*) are with smaller sample size (n<12) and/or over 5 year gaps between samples.

Depth	Season	Pesiöjärvi 2	Pieni-Pesiöjärvi	Uittosalmi
Surface water	Depth	0-2 m	0-2 m	0-2 m
	Winter	1981-2013*	1981-2013*	
	Spring	1987-2017*	1987-2017*	1980-2008
	Summer	1987-2017	1984-2017	1979-2008
	Autumn	1986-2005*	1986-2008*	1982-2008
Lake floor	Depth	> 14 m	> 12 m	> 8 m
	Winter	1981-2013*	1981-2013*	
	Spring	1987-2017	1987-2017	
	Summer	1987-2017	1984-2017	
	Autumn	1986-2005*	1986-2008*	
Entire water pillar	Depth	0- m	0- m	0- m
	Winter	1981-2013*	1981-2013*	
	Spring	1987-2017*	1987-2017*	1980-2008
	Summer	1987-2017	1984-2017	1979-2008
	Autumn	1986-2017	1986-2017*	1982-2008

3 Methodology

3.1 Trend analysis

The flow chart of trend analysis is depicted in Figure 3.1. Before conducting statistical analyses the meteorological and hydrological data were organised into monthly, seasonal and/or annual time series. The analysed data and indices are presented in Table 3.1. Detailed information of the nitrogen concentration time series is available in Table 2.4.

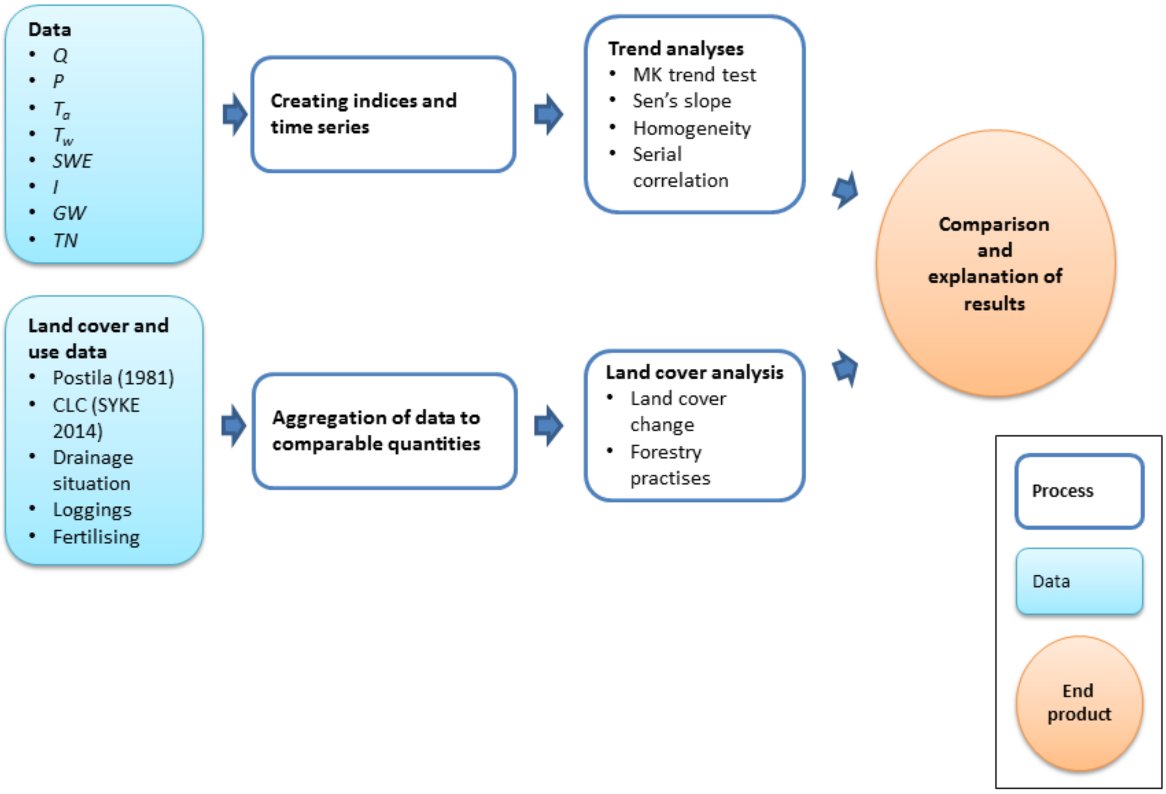

Figure 3.1 The methodology of trend and land cover analyses.

Lake Pesiöjärvi monthly mean discharge (MQ), precipitation (P) and temperature (T) were taken as the average values of a calendar month arranged in chronological time series (Table 3.1). In addition to annual values, the annual high flow (HQ) and low flow (NQ) values were divided into spring and autumn periods. The spring season was from January to June and autumn period from July to December. Seasonal aggregation of surface water temperature and nitrogen were constructed so that winter was December, January, February, spring was March-May, summer was June-August and autumn was September-November. The timing of events, like spring HQ or ice formation, was calculated as days from the first day of the respective year. The trend analysis time series constructed from the total nitrogen samples (Table 2.4) were divided by season and water depth. The three depth categories were surface water (sample depth 0-2 m depth from water surface), lake floor (sample depths 14 m, 12 m and 8 m below water surface in Pesiöjärvi 2, Pieni-Pesiöjärvi and Uittosalmi, respectively) and the entire water pillar.

Table 3.1 List of the quantities and derived indices used in the trend analysis. Discharge indices that showed heterogeneity were split in possible trend change points and existence of trend was tested for the split time series. Full list of indices and results are presented in Appendix 2.

Quantity	Indice	Time period	Note
Discharge	Monthly MQ	1980-2017	Some time series were investigated in fragments due to heterogeneity
	Annual MQ	1980-2017	
	Annual HQ	1980-2017	
	Spring HQ	1980-2017	
	Spring HQ timing	1980-2017	
	Yearly NQ	1980-2017	
	Spring NQ	2012-2017	
	Autumn NQ	1980-2017	
Precipitation	Monthly mean P	1981-2017	Uncorrected, constant corrected and model corrected P
	Annual mean P	1981-2017	
Air temperature	Monthly mean T	1979-2017	
	Annual mean T	1979-2017	
Water tempera-ture	Seasonal water surface T	1985-2018	From temperature probe data
SWE	Modelled max value	1990-2013	
	Measured max value	1981-2018	
Groundwater	Timing of autumn max GW table elevation	1979-2017	
Lake ice cover	Ice formation date	1992-2017	
	Thaw date	1993-2018	
	Duration of ice cover	1993-2018	
	Max thickness of ice	1993-2018	
Nitrogen	Total nitrogen concentration	- -	Seasonally for three sampling points; surface; lake floor; and full depth

The data and indices were analysed for monotonic trend with the Mann-Kendall (MK) non-parametric trend test (Mann 1945; Kendall 1975) and the magnitude of the trend was analysed with the non-parametric Sen's slope estimate (Sen 1968). Both tests have been used extensively in Finland and globally for meteorological, hydrological and hydrochemical trend analysis (Tuomenvirta 2004; Jylhä et al. 2004; Korhonen & Kuusisto 2010; Tattari et al. 2017, Bayazit 2015).

MK test is a hypothesis test where the null hypothesis is that the data is randomly arranged. MK test is performed by calculating Kendall's rank correlation τ statistic and null hypothesis is rejected if the statistic is far enough from 0. The Kendall's τ compares each of the points against each other and compares the ranks, thereby inspecting monotonic correlation of the data pairs of quantity-time. Sen's slope estimate on the other hand calculates the median slope between all the data points of a time series and its significance level (p-value) is the same as for MK tests (Helsel & Hirsch 2002; Sen 1968).

MK test results are sensitive to heterogeneities and serial correlation of the time series. Heterogeneity means the existence of a break point in the data before or after which the time series exhibit a trend (or no trend) different from the other part. Serial correlation describes the tendency of high values following high values or vice versa. Therefore discharge time series were tested for homogeneity by the Pettitt's non-parametric change point detection test (Pettitt 1979) and serial correlation by the first order Breusch-Godfrey test (Breusch 1978; Godfrey 1978). The time series apart from discharge were inspected against heterogeneity by the Standard Normal Homogeneity Test (SNHT) (Alexandersson 1986), which has been used in Finland for change point detection in climatic time series (Tuomenvirta 2002).

If serial correlation is present in the time series, Mann-Kendall trend test rejects null hypothesis more often than with independent data (Bayazit 2015). Therefore the serially correlated time series were treated with prewhitening to remove the serial correlation before performing MK test. In addition, since prewhitening can reduce the ability of MK test to detect an existing trend (Yue & Wang 2002), a comparison was made by performing a modified MK test presented by Hamed and Rao (1998) on the serially correlated time series.

Non-parametric tests are ideal for hydrological and hydrochemical data because they are robust, do not assume data normality and are less sensitive to outliers. However, they can be less powerful than the parametric tests. In addition, MK trend test includes two types of errors attributed to every hypotheses testing. Type I error means that a trend is falsely detected when none exists. Type II error means failure to detect an existing trend. Type II error can occur e.g. because of weakness of testing procedure or the trend or shortness of time series. The test significance level (i.e. the p-value) expresses the probability of type I error. (Kundzewicz and Robson 2004)

The interpretation of the significance of the results is specified in Table 3.2. For trend tests (Mann-Kendall and Sen's slope estimation), the significance level has been split into three categories to provide more diverse results and to better avoid type II error. This method derives from an idea that it is less desirable to not detect a trend when one is present than vice versa, which has recently gained ground in the debate of statistics in water resources (Hirsch 2017). The idea of using broader scale of limit p-values was previously suggested by e.g. Gavrilov et al. (2016). Nevertheless, in this work the limit of significant trend was assigned to $p < 0{,}05$ so that the results were easily comparable to past trend analysis studies especially in Finland. Homogeneity and serial correlation have been divided to only significant or non-significant with p-value limit of 0,05.

Table 3.2 Interpretation of the significance of the statistical tests. The different significance in the tabulated trend analysis results is displayed with different font styles.

Test	p-value	Indication
Trend (Mann-Kendall and Sen's slope)	**p < 0,05**	**Significant**
	0,05 < p < 0,1	Likely significant
	0,1 < p < 0,2	*Possibly significant*
Homogeneity (Pettitt's test or SNHT)	p < 0,05	Significant
	p > 0,05	Non-significant
Serial correlation (Breusch-Godfrey test)	p < 0,05	Significant
	p > 0,05	Non-significant

The statistical tests were done in R Studio software (R Core Team 2017) using existing scripts. The scripts for the MK, Sen's slope, Pettitt's and SNHT tests were from package 'trend' (Pohlert 2018), the script for Breusch-Godfrey test was from package 'lmtest' (Zeileis & Hothorn 2002) and the script for modified MK test as well as prewhitening procedure with MK test were from package 'modifiedmk' (Patamkuri 2018).

The results present the significance of the MK test along with the trend magnitude, as well as information of whether significant heterogeneity or serial correlation exists in the time series. The trend magnitude was calculated from Sen's slope estimate by dividing the slope with mean value of the time series, thus acquiring a % / year change magnitude. If a significant change point was observed in the time series, the time series were split at the break point and MK test and Sen's slope estimate was performed on the fragmented time series. In addition, the discharge time series were split at 2011 due to the possible heterogeneity caused by change of the rating curve. If serial correlation was present in discharge time series, the results displayed in this work nevertheless showed the significance and magnitude of trends for only unmodified non-prewhitened time series. This is because considering the small size of the catchment it was unlikely that the discharge values exhibited significant serial correlation separate from a trend or climate pattern (Koskela, pers. comm. 2018).

3.2 Land cover analysis

The analysis of land cover change in the area of Pesiöjärvi catchment was done by comparing the proportions of different land cover types given in Postila (1981) and CLC (SYKE 2014) in Pesiöjärvi catchment (Figure 3.1). Similarly, forestry practices in the area were analysed as past-present comparison, but with limitations due to missing data. Proper analysis of change of intensity in forestry practices was only possible for drainage operations.

The current land cover situation was analysed by overlaying the CLC raster data (SYKE 2014) with polygon layer including the Pesiöjärvi catchment and sub-catchments and tabulating the area of each land cover classification in the respective catchment. The required catchment and overlay analyses were executed with ArcMap-software (ESRI 2017). The Pesiöjärvi catchment and sub-catchments were outlined with a specified VALUE - catchment delineation tool developed in SYKE (SYKE 2017) and the land cover and soil type analyses were done with tools available with advanced or Spatial Analyst licenses.

The comparison of the past and current situation in Pesiöjärvi catchment was not straightforward, because the 1980 land cover analysis used different definitions compared to CLC. For instance, the definitions for forest types in Postila (1981) were derived from traditional forest and swamp type classification, whereas CLC classified forest first according to tree trunk height and canopy cover, which determine whether the area is forest or transitional woodland, and then according to soil type (mineral soil, peatland or rocky soil) (SYKE 2016).

The most considerable difference in the land cover analysis was in the definitions of the amounts of forested areas on different soil types. This applied especially to forests on peatlands, which in Postila (1981) was categorized with the Finnish terms "*korpi*" and "*räme*", which according to Laine et al. (2012) can be translated as spruce swamp and pine swamp. The density of the forest on the peatland areas of "*korpi*" and "*räme*" was not specified and thus it could have been included into both forest and transitional woodland categories in CLC definitions. Also, it is possible that areas that have been classified as “*korpi*” or “*räme*” did not have peatland soil, since the land cover types were categorized by sight approximation. This brought to question whether it is feasible to compare the “*korpi*” and “*räme*” classification with the CLC forested area on peatland classes. In this work it was nevertheless assumed that the comparison is feasible. To provide more support for this assumption, overlay analyses including soil type information from GTK (GTK 2009) and marsh areas from MML (MML 2017) were included (see Section 2.2). The method of combining the different land cover data is shown in Table 2 (Appendix 3).

3.3 *Water budget analysis*

3.3.1 Lake water budget

The methodology of the lake water budget analysis is depicted in Figure 3.2.

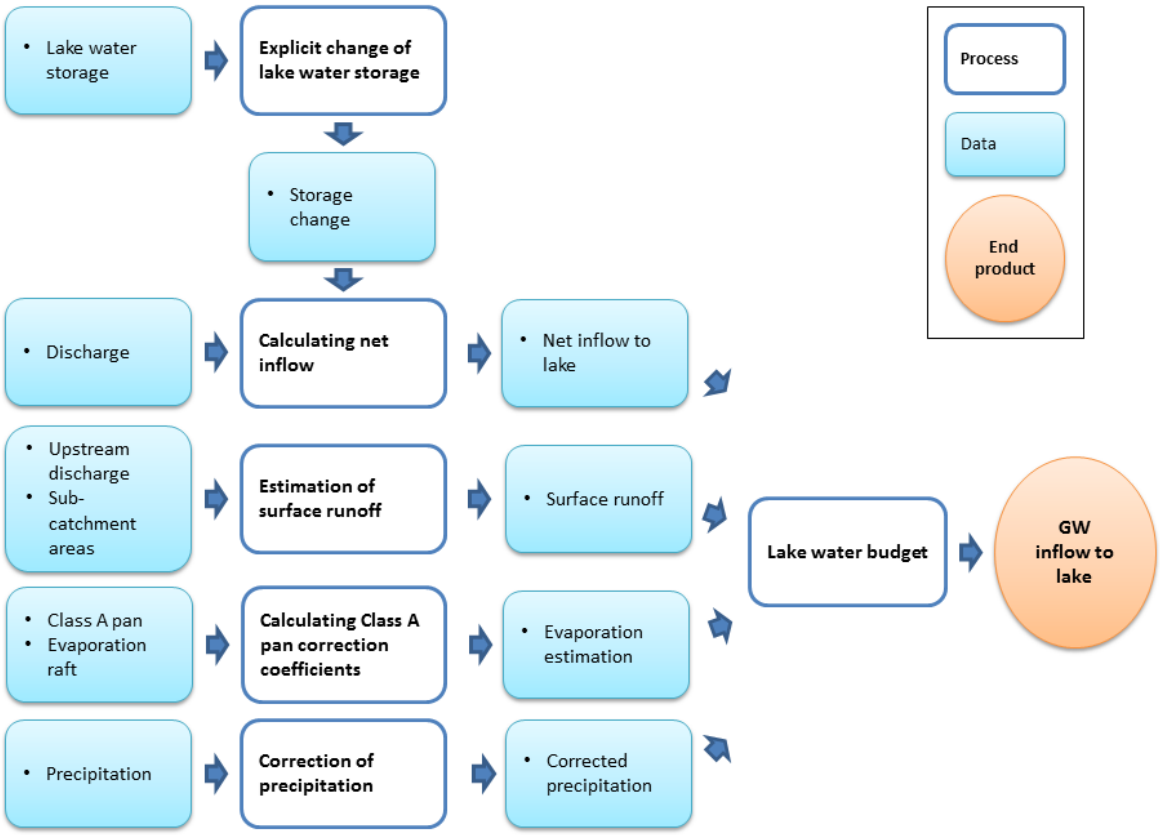

Figure 3.2 The methodology of the lake water budget analysis

Lake water budget included the input and loss terms of water to and from the lake and was estimated as

$$Q_{netin} = Q_{out} + \Delta S_{lake}, \tag{3.1}$$

where Q_{netin} is net inflow in m^3/d, Q_{out} is discharge from Lake Pesiöjärvi in m^3/d and ΔS_{lake} is the change in lake water storage in m^3/d (see Section 3.3.2). Q_{netin} included all water sources and loss term to and from the lake apart from lake discharge. Groundwater flow was calculated from Q_{netin} as

$$I = Q_{netin} - P + E - R, \tag{3.2}$$

where I is flow of groundwater in and out of lake in m^3/d, P is precipitation to the lake in m^3/d, E is lake evaporation from the lake in m^3/d, and R is surface runoff from the catchment to the lake in m^3/d. When I was positive, flow direction was from aquifer to lake.

The lake water budget was calculated in daily interval and the results were presented as monthly averages. In addition, the annual mean values were calculated from the monthly averages, i.e. as weighted averages over the year by calendar months, so that more observation days in spring and summer compared to autumn did not bias the annual average values.

Since evaporation and precipitation occurred directly from and to the lake and no evaporation or precipitation was assumed to influence the lake water budget when the lake was frozen, this was accounted for by multiplying the values of evaporation and precipitation with either 0 or 1 depending on whether the lake was frozen or not. The information of lake ice cover was acquired from direct observations at the place of water level gauge and the date of freeze or thaw was thought to be the date when no water or ice was in sight. If no information of lake ice cover was available, the 1992-2017 average freeze or thaw date was used, which were 2 November and 17 May, respectively.

Melt of snow was not included into the water budget analysis since it was thought to be included in the surface runoff from the areas surrounding Lake Pesiöjärvi. Thus, the only snow melt component affecting the water budget was the snow directly on top of the lake surface. However, this was as well neglected in the water budget analysis, due to the estimation difficulty. The influence of snow melt on the lake water budget was however considered as an error source. The possible influence of snowmelt in the daily water budget in spring was estimated from the average annual maximum SWE divided by days of melt period, to acquire the average daily input of snowmelt to the lake. The melt period was estimated as the days between average maximum SWE occurrence and average end of lake ice cover.

3.3.2 Change of lake water storage

Change of lake water storage in m^3/d was calculated explicitly as

$$\Delta S_{lake} = \frac{S_{lake,t+1} - S_{lake,t},}{(t+1) - t} \tag{3.3}$$

where $S_{lake,t+1}$ is lake water volume in m^3 at time t+1 and $S_{lake,t}$ is the lake water storage in m^3 at time t. The time step $(t+1)-t$ is in d.

The volume of lake was calculated from the lake Pesiöjärvi volume profile (Appendix 1, Table 1) retrieved from Hertta – Environmental database. The volume of the lake was calculated by depth probing and was given in 1 m depth interval, from depth of 0 to 15 m. The depth 0 m is located 213.90 m above sea level in N2000 altitude system. Since the water level of Lake Pesiöjärvi varied between -0,23 and +0,87 m from the 0 m probing depth, the change of volume of the lake was assumed to vary linearly according to the change between depths 0 and 1 m. The linear fit between lake volume and water level yields the equation

$$S_{lake} = 10\,787\,040W + 50\,157\,980, \tag{3.4}$$

where S is the lake volume in m^3 and W is water level measurement in m deducted with the difference of the probing level and the 0-point of the water level gauge in N2000.

Similar linear extrapolation was done for lake area A_{lake} (Appendix 1). The equation between lake area and water level is

$$A_{lake} = 3\,379\,500W + 12\,740\,600, \tag{3.5}$$

where A_{lake} is lake area in m^2.

3.3.3 Runoff to Lake Pesiöjärvi

Runoff to Lake Pesiöjärvi was estimated from the sum of the gauged upstream discharges. This approach was suggested previously by e.g. Virta (1981) and Rosenberry et al. (2015). The runoff included all water that streams gathered from their specific sub-catchments and thus included surface and subsurface flow from the land areas to the upstream water bodies.

Assuming that the runoff value from the gauged sub-catchments represents the whole catchment and weighting it with the difference in area of the gauged sub-catchments and whole catchment runoff area, the total runoff for the whole catchment was acquired as

$$R = k_{area} \sum Q_{sub-catchment} \tag{3.6}$$

$$k_{area} = \frac{A_{Catchment}}{A_{gauged}}, \tag{3.7}$$

where R is surface runoff to lake in m^3/d to Lake Pesiöjärvi, $\sum Q_{sub\text{-}catchment}$ is the sum of discharge measurements from upstream sub-catchments, k_{area} is a factor calculated as the ratio of the catchment total area from where surface runoff flows to Lake Pesiöjärvi, i.e., the catchment area deducted with area of Lake Pesiöjärvi ($A_{catchment}$) and the area of discharge gauged sub-catchments (A_{gauged}). The value of k_{area} is 1,42.

The gauged and non-gauged areas creating runoff to Lake Pesiöjärvi are shown in Figure 3.3. It is to be noted that the non-gauged runoff area included two sub-catchments with lakes: lakes Vaatojärvi and Joutenjärvi, but these were small and comparable to other similar sub-catchments with discharge measurements like Itäjärvi and Mustajärvi. Land cover of the gauged and non-gauged runoff areas and that of all of Pesiöjärvi catchment excluding the lake is shown in Table 1 (Appendix 4). The shares of land cover categories between the separate areas fell within 2 % difference from each other, and thus from the point of view of land cover, the gauged runoff area was considered to describe the whole catchment surface runoff conditions sufficiently well.

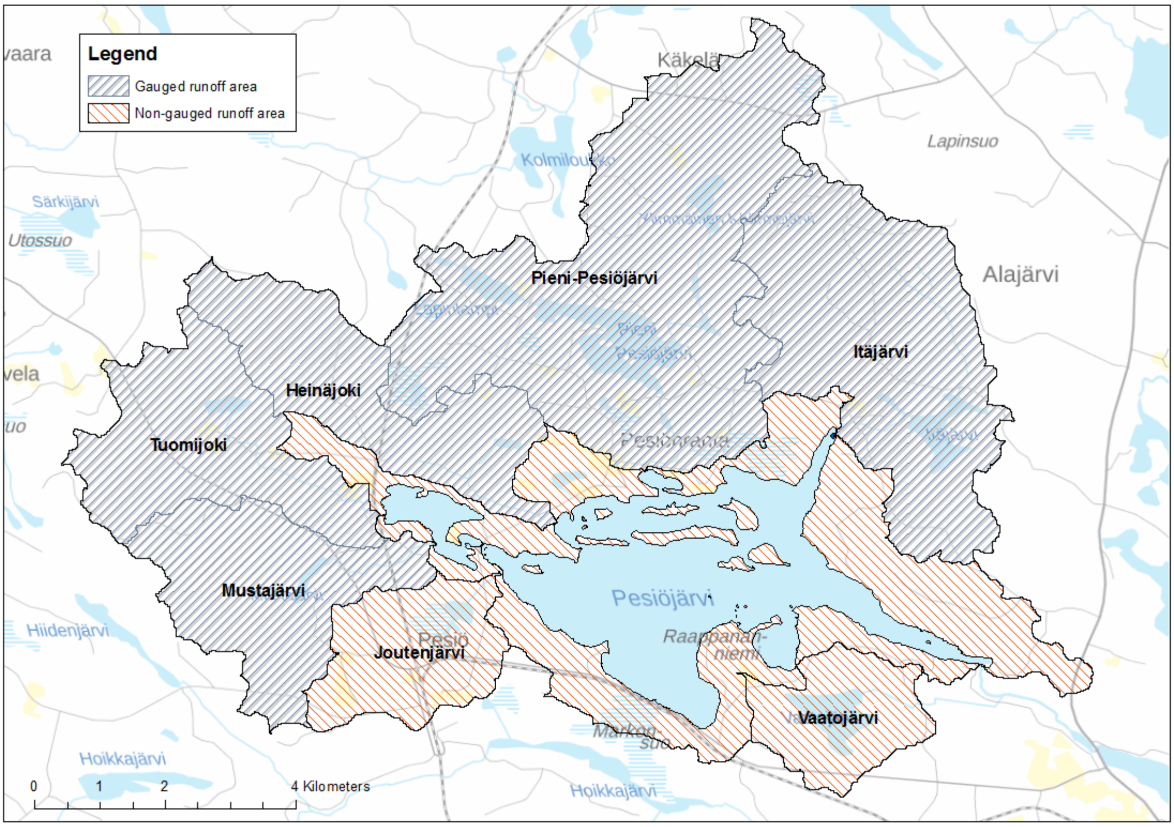

Figure 3.3 Map of the water level and discharge gauged and non-gauged sub-catchments of Pesiöjärvi.

3.3.4 Evaporation

Evaporation was estimated by correcting the daily Class A pan evaporation measurements with monthly correction coefficients. The coefficients were derived as the ratio of lake evaporation estimated by bulk aerodynamic method and Class A pan evaporation. The method was used previously in Finland in studies concerning lake water budget and lake evaporation (Järvinen 1978; Stenberg 2007).

To calculate the correction coefficients for each summer month, lake evaporation was first calculated with the bulk aerodynamic method as described by Järvinen and Huttula (1982) using the raft measurements. There were a few possibilities to choose from different calibrations of the basic equation. In this work the Shuliakovki's equation for lake evaporation was used since it was described by Järvinen and Huttula (1982) as being suitable in Finnish conditions. The Shuliakovski equation for lake evaporation is

$$E_{lake} = (0{,}15 + 0{,}108u)(e_0 - e_2), \tag{3.8}$$

where E_{lake} is the lake evaporation in mm/d, u is wind speed at the height of 2 m above the water surface in m/s, e_0 is the saturation vapour pressure in mb which corresponds to the surface temperature of lake water, and e_2 is the water vapour pressure in mb at the height of 2 m above the water surface. The vapour pressures e_0 and e_2 were calculated with the Tetens equation given by Murray (1967) as

$$e_0 = 6{,}1078 e^{\left[\frac{17{,}2693882 T_w}{(T_w + 273{,}16) - 35{,}86}\right]}, \tag{3.9}$$

and

$$e_2 = 6{,}1078 e^{\left[\frac{17{,}2693882 T_a}{(T_a + 273{,}16) - 35{,}86}\right]} \frac{RH}{100}, \tag{3.10}$$

where T_w and T_a are surface water and air temperatures, respectively, in degrees Celsius, and RH is relative humidity in percent.

The acquired lake evaporation values were then averaged to daily evaporation and again averaged over months together with the pan measurements from same dates. Averaging these yet again over the measurement years, monthly mean lake and pan evaporation values were acquired. The monthly correction coefficient f_{month} for June, July, August, September and October was calculated as

$$f_{month} = \frac{E_{lake,month}}{E_{Class\ A,month}}, \tag{3.11}$$

where E_{lake} and $E_{Class\ A}$ are the monthly average lake and pan evaporations, respectively, over the years 1987 and 1991-1993. For May, since there were no raft measurements present, the correction coefficient was calculated from a similar coefficient for Lake Pääjärvi given in Stenberg (2007, Table 5). The Lake Pääjärvi coefficient for May was multiplied with the average ratio of June-October coefficients derived here and coefficients given in Stenberg (2007) for the same months as

$$f_{May} = f_{May,Pääjärvi} \frac{1}{n} \sum_{i \in Jun-Oct.}^{n} \frac{f_{month,i,}}{f_{Pääjärvi,i}}, \tag{3.12}$$

where $f_{May,Pääjärvi}$ is the Lake Pääjärvi correction coefficient for May according to Stenberg (2007).

The daily lake evaporation used in the water budget analysis was thus calculated as

$$E = f_{month} E_{Class\ A} A_{lake}, \tag{3.13}$$

where E is corrected lake evaporation in m^3/d and $E_{Class\ A}$ is Class A pan evaporation in m/d.

3.3.5 Precipitation

Since throughout the water budget time period precipitation was measured with the same type of gauge (H&H modified Tretyakov), it was feasible to use constant coefficients for correcting liquid and solid precipitation amounts. Precipitation to Lake Pesiöjärvi was calculated as

$$P = (P_l C_l + P_s C_s) A_{lake}, \tag{3.14}$$

where P_l and P_s are the uncorrected liquid and solid precipitation gauge measurements, respectively, in m/d and C_l and C_s are the correction coefficients for liquid and solid precipitation gauge measurements. The description of the estimation of shares of liquid and solid precipitation is described in Section 2.3.4.

4 Results and discussion

4.1 Trend analysis

4.1.1 Observed trends

Seasonal MQ test revealed significant positive trend in winter MQ in 1980-2017 and possible positive trend in 1980-2002 time series (Figure 4.1). Monthly MQ, when it was tested for the full observation period 1980-2017, exhibited significant positive trends for January-April (Figure 4.2 - Figure 4.5) and December. Lake Pesiöjärvi annual MQ and HQ did not show any trends. However, splitting the time series in 2011 (renovation of lake discharge point), and the change point indicated by Pettitt's test for the respective indices, decreased the significance of the test results in the discharge time series. Of the monthly time series split at the respective Pettitt's change points, only March MQ displayed a significant positive trend after change-point in 1991, with similar trend magnitude than for whole observation period (Figure 4.4), and April MQ showed similar but only possibly significant positive trend after change point in 1988 (Figure 4.5). Winter MQ revealed no trend after and a trend of decreased magnitude compared to full observation period before Pettitt's change point in 2003 (Figure 4.1).

For the MQ time series split at 2011, all the monthly MQs except for December and April had same results: significant positive trend in 1980-2010 and no trend in 2011-2017 (Figure 4.2 - Figure 4.5). In December none of the split time series showed significant trend and in April, although only possibly significant, there was a positive trend in both before and after 2011 time series. The magnitude of the trend in all monthly MQ situations was between 1-1,7 % / year, except for April MQ's 2011-2017 time series which was an order of magnitude higher than the rest, although the shortness of the time series casted doubt on the reliability of the result.

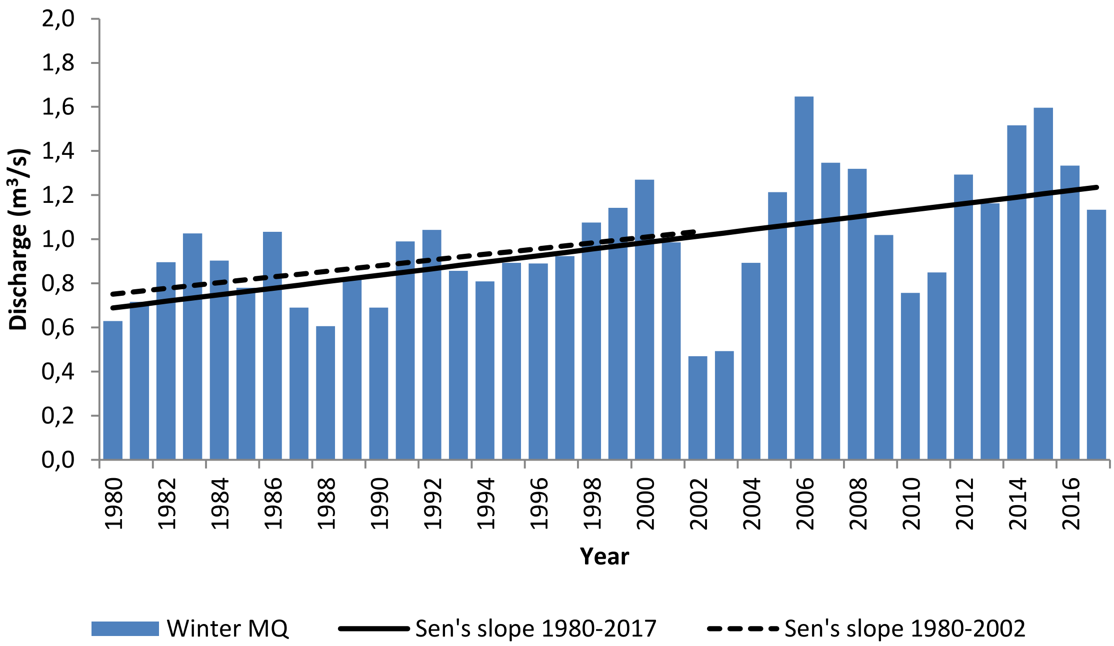

Figure 4.1 Winter MQ and Sen's slope estimates for time series 1980-2017 and 1980-2002 Lake Pesiöjärvi.

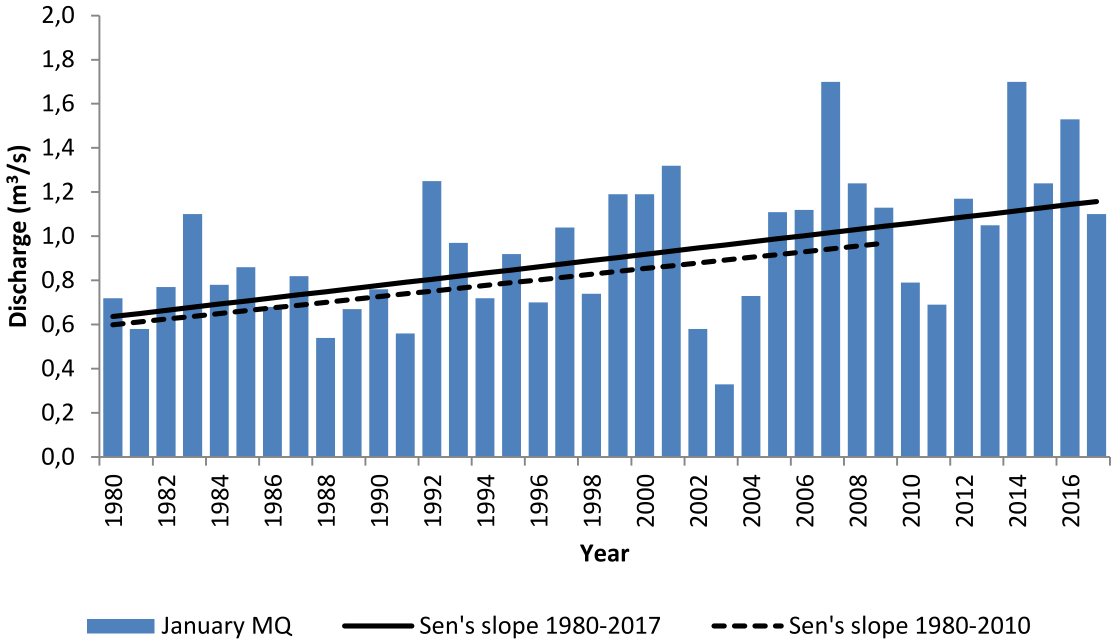

Figure 4.2 January MQ and Sen's slope estimates for time series 1980-2017 and 1980-2010 in Lake Pesiöjärvi.

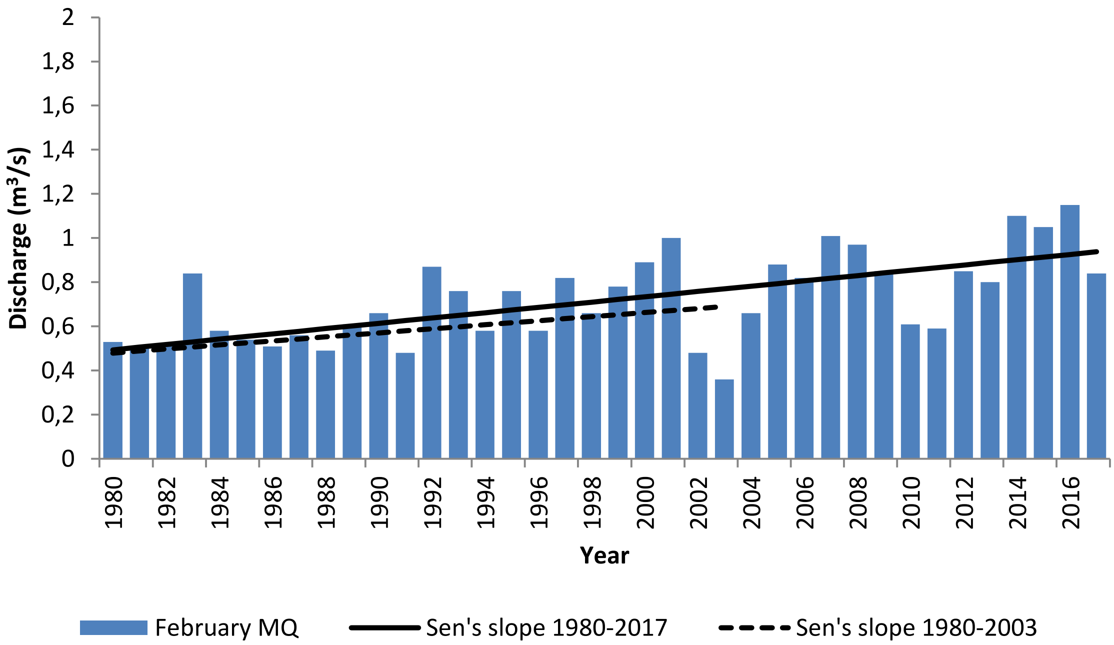

Figure 4.3 February MQ and Sen's slope estimates for time series 1980-2017 and 1980-2003 in Lake Pesiöjärvi.

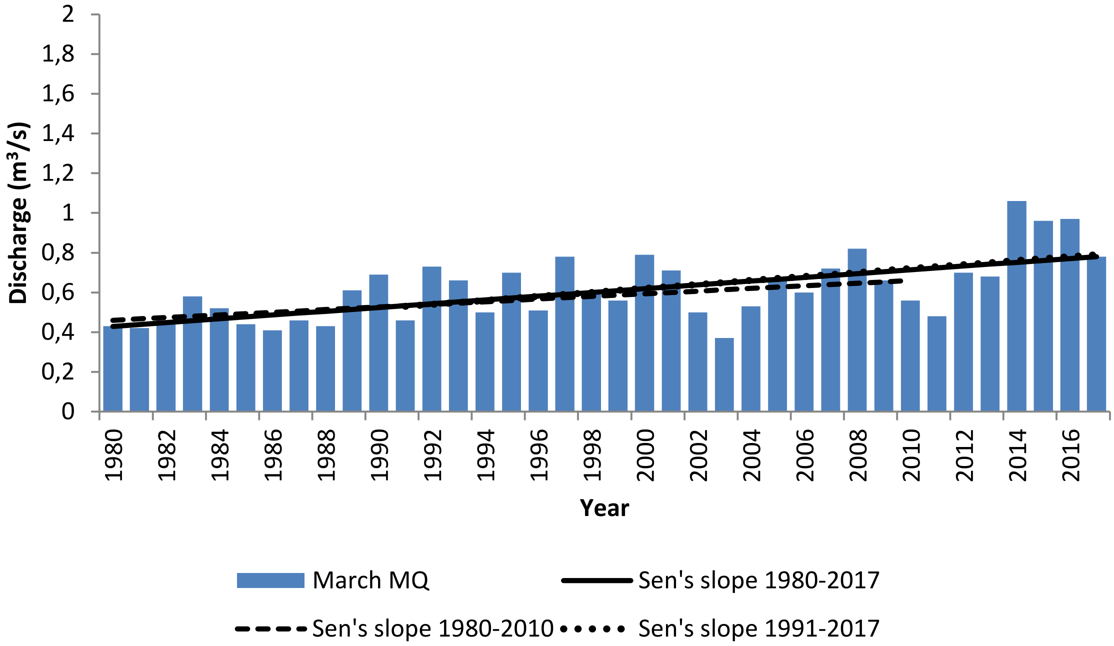

Figure 4.4 March MQ and Sen's slope estimates for time series 1980-2017, 1980-2010 and 1991-2017 in Lake Pesiöjärvi.

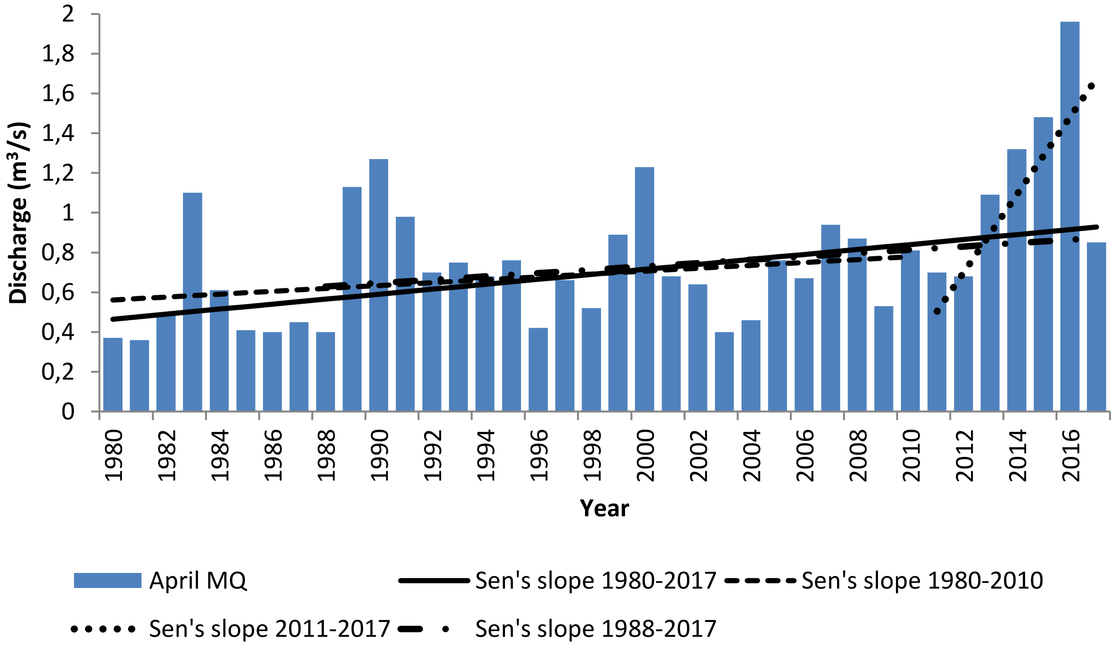

Figure 4.5 April MQ and Sen's slope estimates for time series 1980-2017, 1980-2010, 1988-2017 and 2011-2017 in Lake Pesiöjärvi.

NQ situation was inspected in three different scenarios: annual NQ, spring NQ and autumn NQ situations. In addition, similarly to monthly MQ situations, the NQ time series were split in 2011 and the Pettitt's change point (Figure 4.6 -Figure 4.7). The annual and spring NQs exhibited significant positive trends for the entire time series as well as for the 1980-2011 time series. After 2011, annual NQ displayed a likely significant positive trend, while the spring NQ showed no trend. For the time series fragments split at Pettitt's change points, annual NQ displayed possible positive trends for both 1980-2005 and 2006-2017 (Figure 4.6) and spring NQ showed possible positive trend only for 1989-2017 (Figure 4.7). Autumn NQ exhibited no trend. The full results of the discharge trend analyses with p-values and trend magnitudes per year are presented in Tables 1 – 2 (Appendix 2).

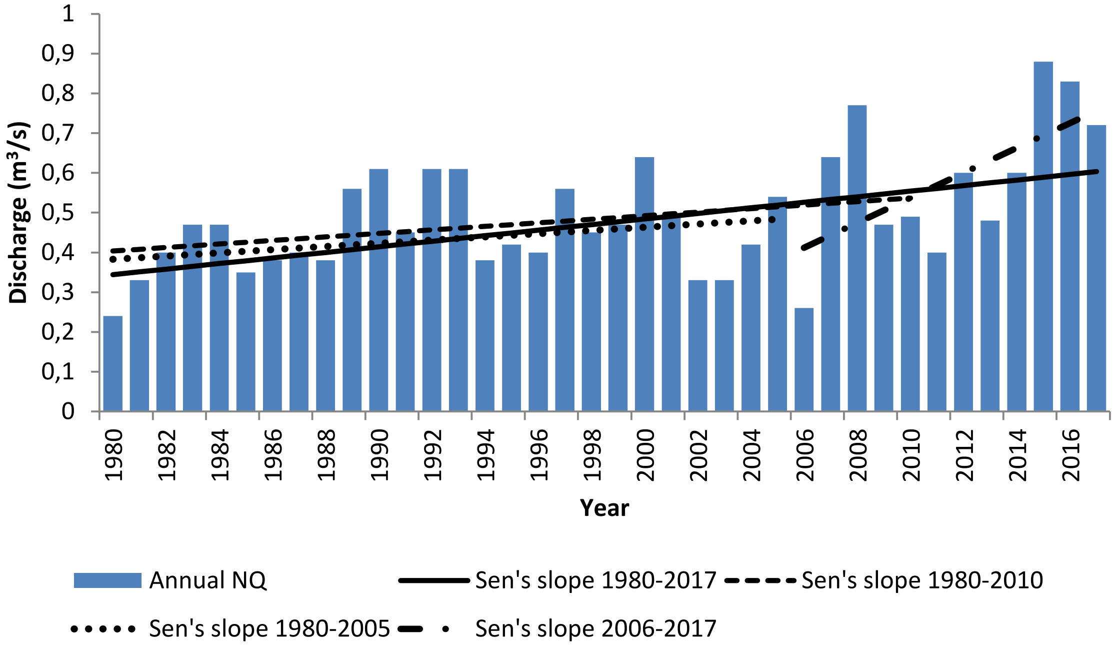

Figure 4.6 Annual NQ and Sen's slope estimates for time series 1980-2017, 1980-2010, 1980-2005 and 2006-2017 in Lake Pesiöjärvi.

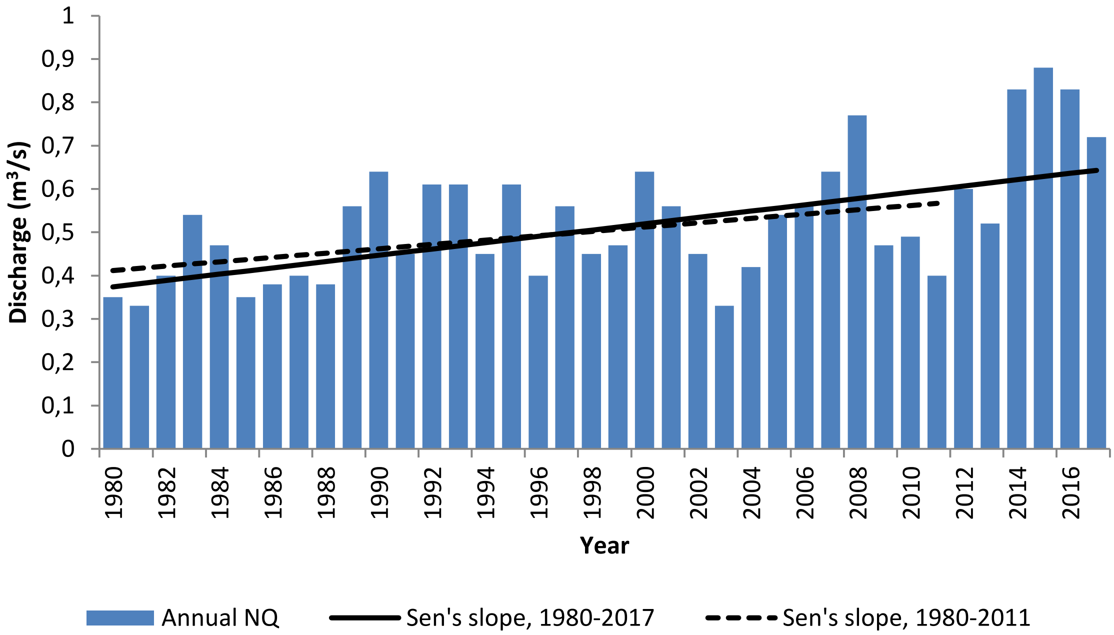

Figure 4.7 Spring NQ and Sen's slope estimates for time series 1980-2017 and 1980-2011 in Lake Pesiöjärvi.

The trend analysis results for quantities apart from discharge are summarised in Table 4.1. Annual mean P showed no trend, but monthly mean P exhibited possibly significant positive trend in August for all precipitation types (non-corrected, constant corrected and model corrected P). In December, model corrected P revealed possibly significant and constant corrected P showed significant positive trend. The magnitudes of the trends were all within 1-2 % / year. Air temperature exhibited significant positive trend for monthly mean air T in August, September, November and December, as well as annual mean air T. The magnitude of the trends were around 0,5 % / year early in the autumn, around 2 % / year in November and December and over 3 % / year in annual mean air T. Surface water temperature displayed significant positive trend in autumn, while the measured max SWE and thaw date revealed possible negative trends, indicating less snow and earlier thaw in spring. The full results with trend magnitudes and p-values are shown in Table 3 in Appendix 2.

Table 4.1 Summary of the trend analysis results for precipitation, air and water temperature, SWE, lake ice cover and total nitrogen concentration. For interpretation of trend results, see Table 3.2.

Time series			Trend		
Quantity	**Indice**	**Time period**	**Time / type**	**Trend**	**Add. information**
Precipitation	*Monthly mean P*	*1981-2017*	*August*	*Positive*	Non-corrected and constant corrected
	Monthly mean P	*1981-2017*	*August*	*Positive*	Model corrected
	Monthly mean P	*1981-2017*	*December*	*Positive*	Model corrected
	Monthly mean P	**1981-2017**	**December**	**Positive**	**Constant corrected**
Air temperature	**Monthly mean T**	**1979-2017**	**August**	**Positive**	
	Monthly mean T	**1979-2017**	**September**	**Positive**	
	Monthly mean T	**1979-2017**	**November**	**Positive**	
	Monthly mean T	**1979-2017**	**December**	**Positive**	
	Annual mean T	**1979-2017**	**Mean T**	**Positive**	
Water temperature	**Seasonal water surface T**	**1985-2018**	**Autumn**	**Positive**	
SWE	Modelled max SWE	1990-2013		-	
	Measured max SWE	*1981-2018*		*Negative*	
Lake ice cover	Ice formation	1992-2017	Autumn	-	
	Thaw	*1993-2018*	*Spring*	*Negative*	
Total nitrogen concentration	*Lake surface*	*1987-2017*	*Summer*	*Positive*	*Pesiöjärvi 2*
	Lake floor	1987-2017	Winter	Positive	Pesiöjärvi 2
	Lake surface	**1981-2013**	**Winter**	**Positive**	**Pieni-Pesiöjärvi**
	Lake surface	**1987-2017**	**Spring**	**Negative**	**Pieni-Pesiöjärvi**
	Lake floor	1981-2013	Winter	Positive	Pieni-Pesiöjärvi
	Lake floor	*1987-2017*	*Spring*	*Positive*	*Pieni-Pesiöjärvi*
	Entire water pillar	**1981-2013**	**Winter**	**Positive**	Pieni-Pesiöjärvi

Total nitrogen concentration in Lake Pesiöjärvi exhibited possible positive trend in summer for surface water, and likely significant positive trend in spring for lake floor (Table 4.1). Lake Pieni-Pesiöjärvi surface water showed significant positive trend for in winter and decreasing trend in spring, lake floor showed likely and possibly significant positive trends for winter and spring respectively and the entire water pillar showed significant positive trend for winter. The full results of total nitrogen concentration trend analysis with trend magnitudes and p-values are shown in Table 4 in Appendix 2.

4.1.2 Discussion of trend results

Heterogeneity caused by the renovation of lake discharge point in 2011 and the change of rating curve did not appear to be a significant factor in detecting a trend in the time series at least in January, February and March MQs and annual and spring NQs. It was evident that a significant trend was detected from both the whole and before 2011 time series. In addition, Pettitt's test did not indicate a change point close to 2011, although this can be due to Pettitt's test's lower power closer to the ends of the time series (Xie et al. 2013). As for the heterogeneity caused by changes in measurement logging or equipment, only April MQ's Pettitt's change point was close to the year of change in measurement system of 1986 and none are close to 2013, when the station was automatized (see Section 2.3.1). If changes in gauging system were a significant cause for heterogeneity, it would show in other time series as well. Therefore it was likely that the time series were homogenous in relation to changes in gauging system.

Even if the detection of trend was not significantly altered by heterogeneity in the longer time series, the fragmenting of the time series noticeably decreased the significance (p-value) of the result as well as the observed trend magnitude. This phenomenon can have multitude of reasons behind it and was therefore not clearly attributed to any single change or action. For example, the power of MK trend test to detect an existing trend is dependent on both the choice of time period (Korhonen & Kuusisto 2010) and the sample size (Bayazit 2015; Johnson 1999). The choice of time period can influence the trend by including or excluding years of prevalent weather patterns due to atmospheric circulation in the beginning or end of the time series (Kundzewicz & Robson 2004). In Figure 4.1 -Figure 4.7, discharge showed generally higher values starting between 2012 and 2014 until 2017. Therefore it is evident that the exclusion of this period would decrease the trend magnitude and significance and possibly omit them completely as in the case of April or December MQ.

Sample size also influences the interpretation of significance, especially in short time series. In trend analysis this means that if the null hypothesis is truly false and a trend truly exists, by increasing sample size one could achieve as low a p-value as desired (Johnson 1999). On contrary, if sample size is decreased, p-value increases leading to the elevated possibility of type II error. Therefore shortening the time series decreases the acquired significance levels. Similarly, this results in the high uncertainty for MK and Sen's test for very short time series, such as the 2011-2017 time period. Examples of this are the April MQ in 2011-2017 (Figure 4.5) and annual NQ in 2006-2017 (Figure 4.6), where the detected trend slopes are obviously too high and not extrapolatable for the whole time series.

The influence of sample size on the power of the MK test was also the reason for assigning the gradually decreasing significance levels for the trend analysis, in contrast to many previous studies. As argued by e.g. Johnson (1999), Gavrilov et al. (2016) and Hirsch (2017), rejecting trend by arbitrary p-value can lead to not acquiring a clear picture of the true situation. More important is to have the information of how significant results are and what the magnitude of the result is. This information is especially important in the analysis of small individual areas like a single catchment, in comparison to e.g. large riverine system examination where the large area and water amount smooths the differences in separate smaller catchments.

Serial correlation was observed in April MQ and spring NQ 1980-2017 time series. Applying prewhitening to the time series and computing MK test statistics again, the significance of the trends decreased to likely significant. Yue and Wang (2002) report that when sample size and trend magnitude are large enough, serial correlation does not have significant influence on MK test statistics. Removing positive serial correlation by prewhitening removes a portion of the trend and leads to reduced possibility to detect trend while it is present. Therefore the time series were also tested with modified MK test according to Hamed and Rao (1998), which showed no considerable change in the significance of the trends.

It is evident from the results in Section 4.1.1 that in 1980-2017 Pesiöjärvi catchment experienced a positive trend in at least January, February and March MQs as well as annual and spring NQ. The positive trend in winter months was further verified by the positive trend in winter season MQ. April and December MQ trends were possible but questionable, considering the low significance or nonexistence of trends in the split time series. In addition, Pesiöjärvi catchment experienced an increase in early winter precipitation, autumn and early winter air temperatures and autumn water surface temperature, as well as decrease in annual max SWE and earlier thawing period.

Comparing the results to literature in Section 1.2.1, it is evident that the observed trends complied well with previous findings in Finland. Korhonen and Kuusisto (2010) also detected highly significant positive trends in February, March, April and winter MQ and slightly lower significance trend for spring in all of Finland. However, Korhonen and Kuusisto (2010) did not report trends for December or January. Also, they reported decreasing trends in June, July and summer season, which were not observed in Lake Pesiöjärvi. Nevertheless, the results by Korhonen and Kuusisto (2010) showed great variance in the existence of trends by separate measurement sites, which shows that the regionally observed trend does not necessarily apply to every catchment. In addition, the trend magnitudes of the significant trends in Lake Pesiöjärvi discharge were generally higher, even doubled compared to what Korhonen and Kuusisto (2010) reported. This was most likely the cause of longer time series of up to 92 years used in the study, which can moderate the trend.

As for the other trends, spring flood peak timing in Lake Pesiöjärvi did not change to earlier date, in contrast with what was reported by e.g. Korhonen and Kuusisto (2010), Käyhkö et al. (2015) and Blöschl et al. (2017). Annual mean temperature in Pesiöjärvi catchment showed positive trend in accordance with Tuomenvirta (2004), although seasonally Tuomenvirta (2004) found that spring temperatures increased most compared to the autumn and early winter temperature trends detected in Pesiöjärvi catchment. Positive precipitation trend in December complied well with the projected increase in wintertime precipitation reported by Jylhä et al. (2004). Decreasing SWE trend was unsure since its significance is low, and since Hyvärinen (2003) reports that eastern Finland would have had positive SWE trends. However, the time series in Hyvärinen (2003) ends in 2001, after which increasing winter temperatures could have affected snow cover in eastern Finland and Pesiöjärvi catchment as well. Surface water temperatures have been shown to increase in eastern Finland by Korhonen (2002) similarly to what was observed in Lake Pesiöjärvi.

Comparison of the trends observed in this study reveals logic and connections between the series. The positive trend in early winter temperature and precipitation suggested higher precipitation in liquid form, which again increased runoff in winter and spring. This was also seen as increased spring NQ and reduced SWE. The positive trends in total nitrogen in winter in Lake Pieni-Pesiöjärvi and spring in Lake Pesiöjärvi were likely a result of increased leaching due to less snow cover and increased precipitation, as suggested by Koskiaho et al. (2010), although it could also be attributed to the old peatland drainage operations as discussed in Chapter 4.2.2. The decreasing trend in the Lake Pieni-Pesiöjärvi surface water total nitrogen trend was somewhat of an anomaly, since there was no such occurrence in literature, but it could be due to chance caused by chosen sampling times or years.

4.2 Land cover analysis

4.2.1 Land cover change

The most important land cover types, areas and shares of catchment total area in 1980 and 2012 are shown in Table 4.2, with more complete information in Table 1 (Appendix 3). The values used in the comparison were partly aggregates of several categories in the original data (Appendix 3, Table 2). During the time period the amount of forested and peatbog area in the catchment stayed roughly the same. Agricultural area diminished by half, and built area increased four times, although the combined share of agricultural and built area was still less than 4 % of the catchment, which can be considered insignificant.

The most profound differences are found in the amounts of forested area in different soil types (Table 4.2). Forested area on mineral soil increased 7 km^2 or 6 % of the catchment area, while forested area on peatland, as well as peatland area all together, decreased 9 km^2 or 8 % of the catchment area. However, comparing the value of CLC peatland areas in Table 1 (Appendix 3) with soil type and marsh data in Table 3 (Appendix 3) showed that the amount of peat soil area given by land cover and soil type analysis were different. In Postila (1981) the peatland in soil type analysis was 2,2 km^2 smaller compared to land cover analysis. At the same time the GTK soil type data indicated only 30 km^2 of peat soil in Pesiöjärvi catchment (Appendix 3, Table 3), which was 6-8 km^2 less than was present in 1980. The information from GTK however was somewhat approximated and includes higher error margin, since its scale was lower than the other sources. In addition, an overlay analysis of the soil type map with CLC indicated 6,6 km^2 of mixed soil (soil type not defined) that overlayed CLC peatland areas. Therefore, there was possibly a significant part of peat soil that was missing from the GTK soil type data. This was further supported by marshes layer created in SYKE in Table 3 (Appendix 3), that indicated 34,7 km^2 of marshes, which is closer to the area of peatland indicated by Postila (1981) in 1980.

There was a possible error source due to the fact that in Postila (1981) the land cover amount was reported as percentage of the overall catchment area, which for the sake of this comparison has been transformed to km^2 by multiplying with the total catchment area in Table 4.2 and Table 1 (Appendix 3). Therefore the difference in the catchment area used in 1980 and today, which was roughly 0,1 %, could cause some discrepancy in the land cover areas. In addition, Postila (1981) included in the land cover category “built areas” only roads and railways, whereas CLC 2012 (SYKE 2014) included constructions and yards as well. The actual change over time in built areas, which according to the analysis is 1,4 km^2, was most likely significantly less and in 1980 the amount of built areas would have been higher than reported. These error sources could cause the over estimation of the other land cover categories in 1980 by at most 1,4 km^2 or 1,4 % of the catchment area.

After considering all the source materials and the possible error factors, the amount of peatland area diminished by at most 9 km^2, which was 8 % of the whole catchment area and slightly over 20 % of the original peatland area (Table 4.2). The change occurred only in already forested areas and led to similar, yet slightly lower, increase of forested areas on mineral or undefined mixed soil, which increased up to 7 km^2 or 6 % of the catchment area and 16 % increase compared to original boreal forest category (Table 4.2). Most likely the magnitude of the decrease of peatland and increase of mineral soil was equal and the difference in the results was the cause of errors deriving from the differing land cover definitions and source material precision. Considering the relatively small change in land cover it was assumed that the influence of land cover change in the hydrology of Pesiöjärvi catchment was minimal and would not have influenced hydrological trends.

Table 4.2 Description of land cover in 1980 (Postila 1981) and 2012 (SYKE 2014). The values below the dividing line are aggregates of several categories of the original data. The method of aggregating the different categories is presented in Table 2 of Appendix 3.

1980				**2012**		
Land use type according to Postila (1981)	**Area (km^2)**	**% of catchment area**		**% of catchment area**	**Area (km^2)**	**Land use type according to CLC (SYKE 2014)**
Total area	102,5				102,6	
Boreal forests (*Kangas*)	44,8	44 %	>	42 %	43,0	Forest on mineral soil
Peatbogs	5,1	5 %	=	5 %	5,0	Peatbogs
All forested areas	75,7	74 %	=	75 %	76,9	All forested areas
All forested areas on mineral soil	42,6	42 %	<	48 %	49,5	All forested areas on mineral soil
All forested areas on peatland	33,1	32 %	>	24 %	24,4	All forested areas on peatland
Peatland area	38,2	37 %	>	29 %	29,4	Peatland area

4.2.2 Land use and its influence on catchment hydrology and hydrochemistry

In Pesiöjärvi catchment the most influential land use practices were loggings, drainage and fertilisation, which occurred both before and during the measurement period. Postila (1981) reported that 6,1 % of the boreal forest area (2,7 km^2) was past logged area in 1980 (Appendix 3, Table 1). In CLC there was no category for logged forest areas, but the category 3241 Transitional woodland / shrub, canopy cover < 10 % was the closest to represent this, since it also assumed mineral soil as soil type and therefore were more similar to felled boreal forest. In 2012 the amount of this area was 3 km^2, roughly the same as in 1980. However this was not the only truth, since the other transitional woodland categories of CLC, which have canopy cover of 10-30 %, amounted to roughly 12 km^2. This category could also contain past logged forest areas. It seems like the category transitional woodland

/ shrub on mineral soil was more likely past logged areas while the same category on peatland were closer to thin-growing forested peatland similar to spruce or pine swamp. It was assumed that the logging pressure, i.e., the average amount of forest area felled in a year, had not changed significantly over the measurement period and therefore the possible influences to land catchment hydrology or hydrochemistry would have been constant in the time period and had not affected significantly any trends.

Table 4.3 describes the amounts of drained and undrained peatland as absolute area and shares of the catchment area and the total peatland area in 1980 and 2017. The amount of drained peatland after 1980 had increased by over 4 km^2 which equalled 12 % of the whole peatland area in the catchment. Draining peatland could have in some occasions dried the peat soil so that it started to transform to mixed or mineral soil, hence explaining the decrease in peatland and increase in mineral soil categories.

According to Postila (1980) and maps available in SYKE archives, most of the drainage operations in Pesiöjärvi catchment were executed in 1970s, with the largest operations in 1970, 1971 and 1973. The amount of drained land was at most less than 5 %, and on average around 1 % of the catchment area annually. Information of operations on government owned land was not available, but according to Postila (1981) there were no drainage operations planned after 1980. In general drainage of virgin peatlands were rare in Finland after 1980s and totally ceased after 2000 (Kenttämies 2006). Therefore most of the virgin drainage operations in the catchment had occurred either before, or early in the measurement period.

Even if virgin drainage operations were ceased, maintenance of old peatland ditches still occurred in 1980-2017. An on-site visit to Pesiöjärvi catchment in July 2018 revealed signs of ditch network maintenance in the area of Joutenvaara (Figure 4.8). Unfortunately there were no complete records of ditch network maintenance operations and their annual amounts and frequency were not known.

Based on what is discussed in Section 1.2.2 and the fact that most virgin drainage operations occurred roughly 40-50 years ago, it is safe to assume that the influence of peatland drainage had no major influence on the catchment hydrology. However, the influence of drainage on nitrogen export to receiving waters was most likely more significant. According to Nieminen et al. (2017), nitrogen export from drained peatland area would have been close to export from pristine area in 1990-2010, but likely increased, when the time from the first operations was closer to 50-60 years. Considering the high amount of drained peatland already before 1980 (over 20 % of catchment area), the influence of old drained peatland in nitrogen export was likely considerable. This is also supported by Kenttämies (2006), who forecasted that the ditch network maintenance would be the largest contributor to nitrogen loading amongst different forestry practices in 2010.

Fertilisation in Pesiöjärvi catchment has occurred both in agricultural and forest land. The amount of fertilised agricultural land was around 1 % of the whole catchment area (Postila 1981). According to Postila (1981) and archived maps of SYKE describing peatland forest fertilisation projects in Pesiöjärvi catchment, forest fertilisation occurred in 1970-86 annually in an area less than 1 km^2 or 1 % of the catchment total area. The fertilisers were mainly phosphorous and potassium mixtures and urea. The amount of urea spread was 200 kg/ha. Records of the situation in 2017 were not available but it was assumed that the fertilising amounts have stayed similar. However, considering the relatively small areas and amounts of nitrogen containing fertilizers used and the fact that fertilising became better planned and regulated (Kenttämies 2006), it was assumed that peatland forest fertilising did not have significant influence on the catchment scale nitrogen balance or possible trends.

Table 4.3 Drained peatland area in Pesiöjärvi catchment in 1980 and present. The information of the past is based on Postila (1981) and the present situation is according to SYKE (2011).

Description		1980	Present
Sum of peatland	km^2	36,1	34,2
Drained peatland	km^2	21,6	25,8
Undrained peatland	km^2	14,5	8,4
Share of drained peatland from catchment area	%	21	25
Share of drained peatland from catchment peatland area	%	60	75
Share of undrained peatland from catchment area	%	14	8
Share of undrained peatland from catchment peatland area	%	40	25

Figure 4.8 A fresh ditch network maintenance operation in the area of Joutenvaara revealed during a field trip in July 2018. (Photo: Niklas Dahlberg)

4.3 Lake water budget

4.3.1 Estimation of lake evaporation

The monthly mean lake and Class A pan evaporation during the time periods and monthly coefficients for correcting Class A pan evaporation to lake evaporation calculated as in Section 3.3.4, are presented in Table 4.4. Table 4.4 also includes the coefficients presented in Stenberg (2007) for Lake Pääjärvi. It is noticeable that contrary to usual consensus in literature that lake evaporation would be less than pan evaporation due to the warming effect of the sides of the pan (Jensen 2010), the lake evaporation from raft measurements gave higher values of evaporation compared to on-land Class A pan. The high estimate for lake evaporation resulted in average and monthly correction coefficients being considerably larger than 1. In literature common average correction coefficient for Class A pan to lake evaporation is around 0,7 (Jensen 2010), although average values ranging from 0,76 to 1,25 have been observed in Finland for June-September observation period (Järvinen 1978). Comparing the literature values to the average coefficient calculated for Lake Pesiöjärvi, the Lake Pesiöjärvi coefficients were 30 % to 110 % higher depending on source.

The monthly coefficients between Lake Pesiöjärvi and Lake Pääjärvi had large differences as well, although they exhibited a similar pattern of change over the observation period (Table 4.4). Near thaw (May) the raft evaporation was only half of pan evaporation, and around midsummer (June and July) raft evaporation was within 20 % from pan evaporation in both areas. The difference between both lake and pan evaporation and between the two lakes became more pronounced in late summer (August and September), when in Lake Pesiöjärvi the correction coefficient was on average 50 % larger than in Lake Pääjärvi. For October the correction coefficient for Lake Pääjärvi was over six times higher than for Lake Pesiöjärvi.

The large differences between the coefficients of the two lakes (Pesiöjärvi and Pääjärvi) (Table 4.4), as well as between the Pesiöjärvi coefficients and literature values, casted doubt on the feasibility of the lake evaporation estimation for Lake Pesiöjärvi. However, the calculation method and related parameters are sensitive to a range of different affecting factors. First, there can be large discrepancies in the pan evaporation measurements due to the different microclimate at the location of the pan (Kajander 1973). Possible shading of trees and constructions obstruct wind and solar radiation causing noticeable differences even between pans geographically close to each other (Järvinen & Kuusisto 1995). Influence of different climatic conditions, especially air and water temperature, apply also to lake evaporation (Hyvärinen et al. 1973). Second, the differing properties of lakes in question affected the heat storage accumulated during summer period. According to Morton (1967) shallow lakes evaporate more than deep lakes in similar climate due to the easier heating of shallow water bodies, which results in higher water temperatures that accelerate evaporation. In addition, general climatic conditions caused by difference in latitude of the two sites as well as errors in raft and pan measurement data influenced the coefficients.

Considering the influencing factors discussed above, the large coefficients in August and September (Table 4.4) were most likely due to the accumulated heat stored in the lake water, i.e. increase in water temperature. The accumulated heat storage balances the daily fluctuation of the surface water temperature and intensifies daily evaporation. The effect of accumulated heat storage was higher in Lake Pesiöjärvi than lake Pääjärvi due to the considerable difference in lake depth (Lake Pesiöjärvi had mean and maximum depth of 4 and 14 meters respectively while for Lake Pääjärvi the values are 15 and 85 respectively). Thus Lake Pesiöjärvi would have heated more during the summer and maintained higher water temperature compared to the measuring pan that was more affected by air temperature changes. The considerably smaller coefficient for October in Pesiöjärvi was explained by the more northern location of Pesiöjärvi, which caused more abrupt drop in lake water temperature and earlier freezing in autumn. In addition, the Class A pan location in Pesiöjärvi catchment was somewhat sheltered by trees from east to southeast, which caused lower evaporation measurements. This was inspected by comparing the average Class A pan evaporation of Lammi, which is close to Pääjärvi, and Sodankylä in northern Finland and Pesiöjärvi. The average Class A evaporation in Pesiöjärvi in 1980 – 1999 was 0,1-0,3 mm/d smaller than either of the compared.

Table 4.4 Raft and Class A pan evaporation in Pesiöjärvi, and the correction coefficients for pan evaporation in Pesiöjärvi and Pääjärvi. Pääjärvi coefficients are according to Stenberg (2007).

	Evaporation (mm/d)		**Coefficients**		**Ratio**
	Lake (raft)	**Class A pan**	**Pesiöjärvi** (Raft/Pan)	**Pääjärvi** Stenberg (2007)	**Pesiöjärvi coeff. / Pääjärvi coeff.**
May			**0,5** (*)	0,4	
Jun.	2,56	2,76	**0,9**	0,7	1,33
Jul.	3,53	2,87	**1,2**	1	1,23
Aug.	3,09	1,67	**1,8**	1,2	1,54
Sept.	2,45	0,94	**2,6**	1,8	1,46
Oct.	0,33	0,68	**0,5**	3,2	0,15
Average (June-Sept.)	2,39	1,79	1,66	1,18	1,39

(*) *Correction coefficient for May was calculated as the product of average ratio between Stenberg and calculated coefficients and the coefficient for May according to Stenberg (2007)*

To inspect the effect of the calculated coefficients on the estimated evaporation, the monthly mean raft evaporation and Class A pan evaporation corrected with the Pesiöjärvi coefficients were plotted against the same pan evaporation corrected with Pääjärvi coefficients and evaporation acquired from SYKE WSFS model (Vehviläinen & Huttunen 2001) in Figure 4.9. All the curves except the uncorrected Class A pan evaporation followed a similar pattern. It is clear that the Class A pan evaporation estimate, when used raw or corrected with a constant, would have overestimated evaporation in early summer and underestimated it in late summer and autumn. The raft and Pesiöjärvi coefficient corrected evaporation (henceforth Pesiöjärvi evaporation) were generally larger compared to the Pääjärvi coefficient corrected evaporation (henceforth Pääjärvi evaporation) or WSFS evaporation. The Pesiöjärvi evaporation was 23-33 % higher than Pääjärvi evaporation in June-July and 46-54 % higher in August-September. On the contrary, Pesiöjärvi evaporation was closer to the WSFS evaporation in late summer, being 38 % higher in August and 6 % lower in September than the WSFS evaporation. However, in June and July the difference between Pesiöjärvi and WSFS evaporation was as high as 58-78 %, being highest in June. In May Pesiöjärvi evaporation was 15 % higher than both Pääjärvi and WSFS evaporation and in October the situation was reversed with both Pääjärvi evaporation and WSFS evaporation being many times higher than the Pesiöjärvi evaporation. The difference in the annual average of the different evaporations for the full time period of the water budget analysis is

26 % between the Pesiöjärvi and WSFS evaporation and 31 % between Pesiöjärvi and Pääjärvi evaporation.

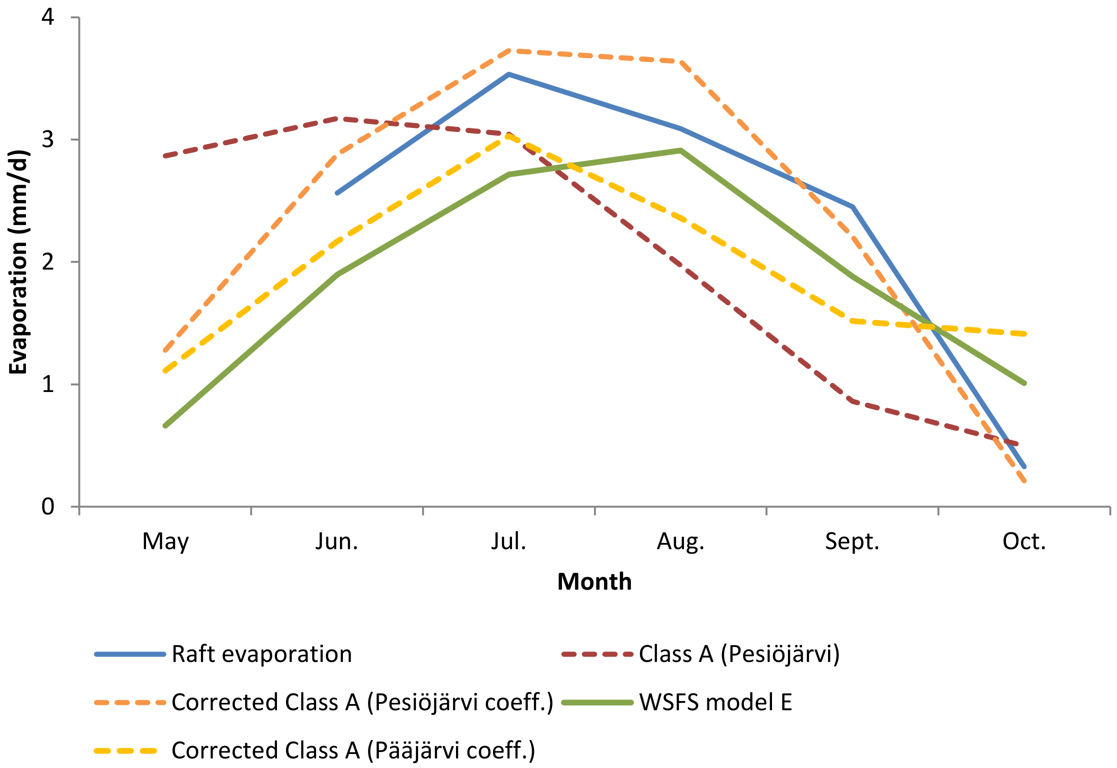

Figure 4.9 Comparison of the raft, Pesiöjärvi Class A pan, corrected Pesiöjärvi Class A pan evaporations and the evaporation calculated by SYKE WSFS model (Vehviläinen & Huttunen 2001).

4.3.2 Groundwater inflow

The annual average GW inflow was around 27 000 m^3/d which was 25 % of the sum of input and loss terms, i.e. net inflow (Table 4.5). Dividing this with the area of the lake resulted in flow rate of 2,1 mm/d of inflow. The other water budget components were as follows: lake evaporation was nearly equal to precipitation, both being 14 % of Q_{netin}, and surface runoff was 75 % of Q_{netin}. Adding evaporation to Q_{netin} the acquired total input term constitutes of 22 % GW inflow, 13 % precipitation and 65 % surface runoff. The amount of GW inflow compares to 1/3 of surface runoff. The annual cycle of all the water budget components is shown in Figure 4.10. Of the components, GW inflow had the least intra-annual variation, but clear increases were visible after snowmelt period and in late autumn and a decrease in late summer or early autumn.

Comparing the GW inflow and the inflow rate to the reported median values summarised in Rosenberry et al. (2015) of the share of GW inflow in Q_{netin} and inflow rate, which were 25 % and 7,4 mm/d respectively (Section 1.3.1), the acquired GW inflow result can be considered to be feasible. Also comparing Lake Pesiöjärvi to other lakes of its size in Rosenberry et al. (2015), the share of GW inflow of Q_{netin} is 5-10 %-units larger in Lake Pesiöjärvi. Of the studies summarised studies in Rosenberry et al. (2015), there were all in all 37 studies that utilised lake water budget, and 15 of them included only GW inflow to lake. Of the studies with only GW inflow present, the range of the share of GW inflow to Q_{netin} was from 0 to 90 % with median and average of 17,8 and 26,4 %, respectively. The acquired result of GW inflow compare well also to these. The relative importance of the different water budget components also compares well to previous research. Both Dalton et al. (2004) and Harvey et al. (2000) found that groundwater inflow to the lake was considerably smaller in quantity than runoff to the lake and slightly greater than evaporation and precipitation.

Table 4.5 The monthly averages of net inflow, evaporation, GW inflow, precipitation and surface runoff in the Lake Pesiöjärvi water budget.

Month	Net inflow 10^3 m^3/d	Evaporation %	GW inflow %	Precipitation %	Surface runoff %
1	59	-0 %	41 %	0 %	59 %
2	47	-0 %	38 %	0 %	62 %
3	37	-0 %	26 %	0 %	74 %
4	153	-0 %	18 %	0 %	82 %
5	334	-2 %	10 %	4 %	88 %
6	131	-32 %	38 %	27 %	68 %
7	61	-90 %	74 %	48 %	68 %
8	42	-136 %	89 %	47 %	100 %
9	77	-31 %	11 %	46 %	75 %
10	130	-0 %	3 %	32 %	65 %
11	118	-0 %	26 %	8 %	66 %
12	88	-0 %	39 %	0 %	61 %
Average (10^3 m^3/d)	107	-15	27	15	80
% of net inflow		-14 %	25 %	14 %	75 %

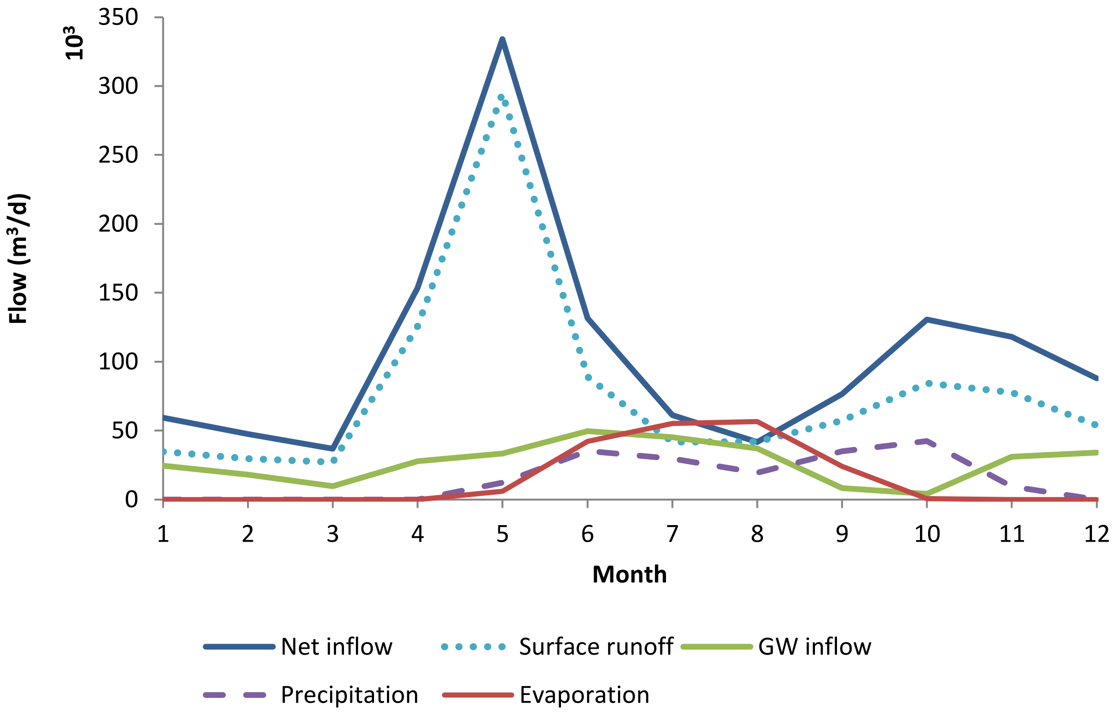

Figure 4.10 The annual cycle of the lake water budget components.

To further analyse the temporal dynamics of GW inflow over calendar year, GW inflow was rendered to an annual cycle of monthly averages over the observation period along with the share of GW inflow from Q_{netin} (Figure 4.11). The result resembled a typical GW hydrograph. Similar annual cycle for a modelled GW inflow in esker aquifer – lake interaction was presented by Ala-aho et al. (2015) and the acquired cycle in Figure 4.11 resembled well the one presented by them, although the timing of the spring and autumn low values of GW inflow differed by 2-3 months. In spring, the GW inflow in Ala-aho et al. (2015) had its spring minimum in May and autumn minimum in August, compared to March and October as elicited in the water budget analysis. The annual maximum occurred in June in both the water budget analysis and Ala-aho et al. (2015). The differences in the results to Ala-aho et al. (2015) were likely due to the different research methods.

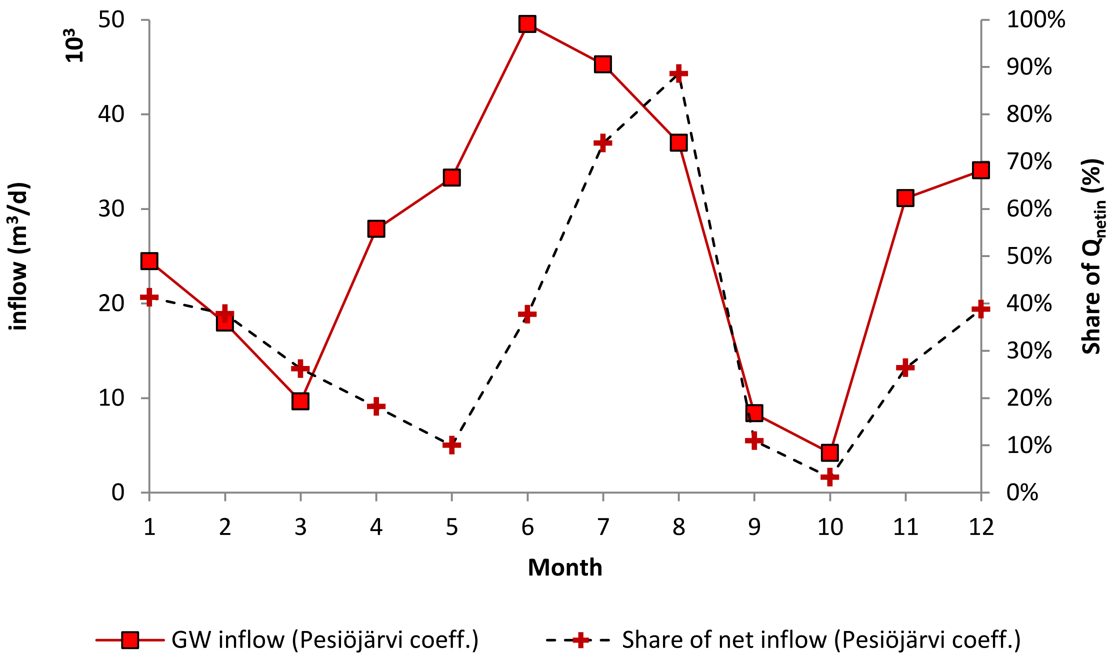

Figure 4.11 Annual cycle of groundwater inflow to Lake Pesiöjärvi and the share of the monthly average GW inflow of Q_{netin}.

In addition, the annual cycle of GW inflow was compared to the monthly average groundwater table elevation of the four groundwater stations and the Lake Pesiöjärvi water level in 1980-2017 (Figure 4.12). The GW table elevation and lake water level were modified so that they fit better in the same plot. In Figure 4.12 the true GW table elevation is higher than lake water level by 3,07 m. The annual cycle of GW inflow tends to follow the changes in the GW table elevation and lake water level and their annual variation was well explained by the changes in the other water budget components such as surface runoff (Figure 4.10). In winter GW inflow decreased as the GW table withdrew due to frozen ground, which inhibits rain water infiltration and GW recharge. In spring, as snowmelt and subsequent GW recharge starts, GW inflow increased rapidly, reaching peak in June. However, the share of GW inflow from Q_{netin} stayed low until May, due to the relative increase of surface runoff generated by snowmelt. After June, GW inflow as well as GW table elevation and lake water level started to decrease while the relative share of Q_{netin} increased over summer because of decrease in precipitation and surface runoff and increase in evaporation. The GW inflow reached its minimum in October as a combined result of the decreasing GW table over summer and increased autumn precipitation and subsequent surface runoff. In late autumn and beginning of winter GW inflow started to increase again. The increase in late year was most likely because of increased GW table elevation, which gave the aquifers improved capacity to release water to the lake. Simultaneously ground frost and snow accumulation decreased surface runoff, which created pressure for GW inflow to replace this flow to the lake.

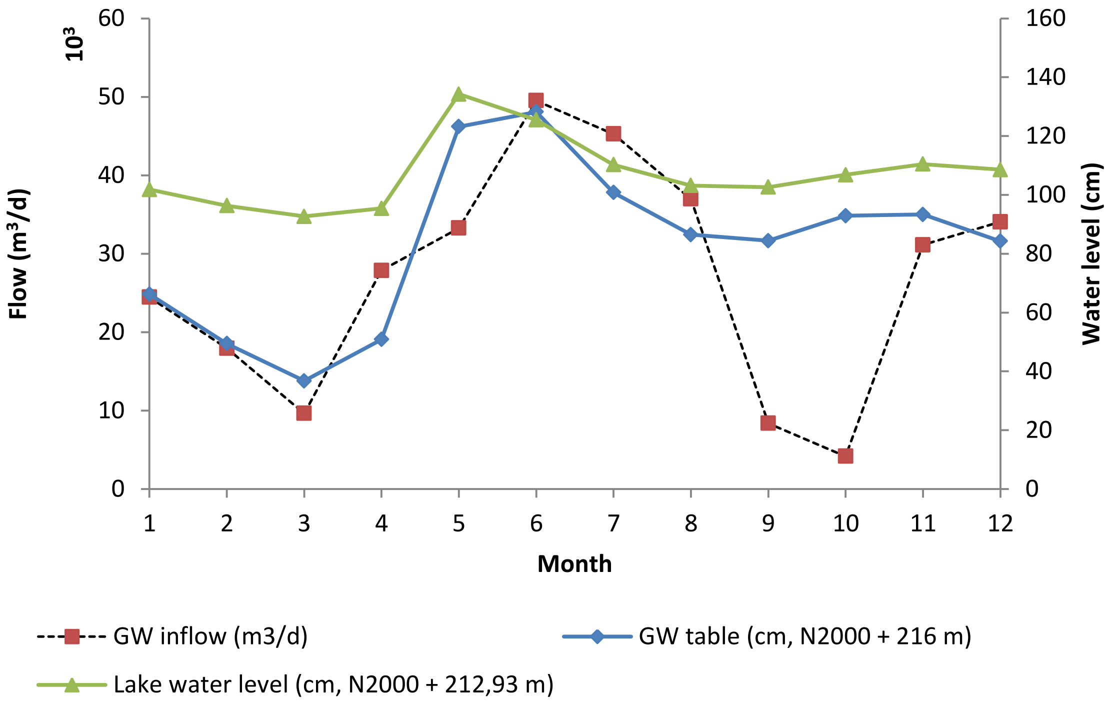

Figure 4.12 Annual cycle of GW inflow, GW table elevation and water level in Lake Pesiöjärvi. The GW table and lake water level have a different datum so that they would better fit in the same plot and are therefore not directly comparative. The true GW table elevation in every month are 3,07 m higher than the water level values.

For comparison of the influence of evaporation in the water budget, the annual cycle of GW inflow was calculated using the WSFS model evaporation and the evaporation acquired with the coefficients from Lake Pääjärvi (Stenberg 2007). The different GW inflows are plotted in Figure 4.13. The monthly differences between the separate GW inflows were quite significant in June to August, ranging from 27 % to over 100 %. In September the GW inflow calculated with WSFS evaporation was very close to the GW inflow with Pesiöjärvi evaporation. In October, GW inflow with Pesiöjärvi evaporation was close to the GW inflow with Pääjärvi evaporation, and ¼ of GW inflow with WSFS evaporation. Noticeable was that the differences especially between GW inflows calculated with Pesiöjärvi and WSFS evaporation were large enough to change the locations of the spring maximum and autumn minimum GW inflow earlier by one month. The differences in the shares of the different GW inflows to the Q_{netin} were nevertheless low, with only July and August displaying difference of over 15 %.

The ratio of the annual average GW inflow calculated with model and Pääjärvi evaporation to the annual average Q_{netin} was 22 %, which was only 3 %-units lower than the GW inflow calculated with Pesiöjärvi evaporation. Therefore it was concluded that, when inspecting the large scale averages of GW inflow in such lake systems where GW contribution is significant, evaporation has only minor influence. More important in the increase of accuracy would be to improve the estimation of lake water storage change and surface runoff. Similar results were reported in e.g. Dalton et al. (2004). However, if the attention of the study is in the intra-annual dynamics of GW-SW interaction, evaporation becomes more important and can remarkably alter summer and autumn flows or the timing of the peak and low values.

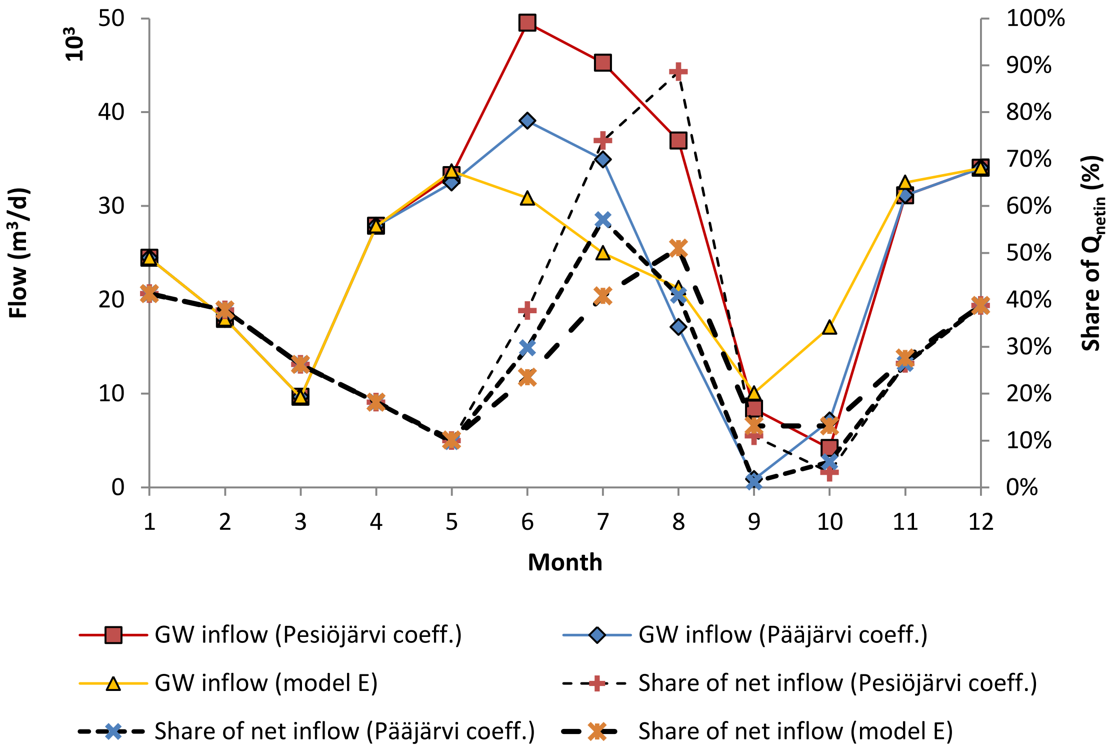

Figure 4.13 Annual cycle of GW inflow calculated with three different evaporation estimates: Class A pan evaporation corrected with Pesiöjärvi and Pääjärvi correction coefficients and SYKE WSFS model evaporation and their respective shares of Q_{netin}.

To quantify the possible error in neglecting snowmelt on top of the lake, the average rate of snowmelt induced flow in spring was calculated. The mean maximum SWE in 1991-2002 in the snow course stations close to the shore of Lake Pesiöjärvi (Jokiniemi and Vaatojärvi) was on average 178 mm. In the same stations the maximum SWE occurred on average in the beginning of April. Assuming that the melt of snow on top of the ice occurred gradually from the average peak day until the end of ice period in 17 May (period of 47 days), the snowmelt added roughly 48 000 m^3/d of water into the lake water budget. Comparing the average melt rate to Q_{netin}, snowmelt was 31 % of April, 14 % of May and 20 % of April-May average Q_{netin}. More striking is that the rate of melt exceeded GW inflow for both April and May, possibly plunging GW inflow to 0 or even negative. However this was nevertheless questionable, since the calculated melt rate was liable to overestimation due to several reasons. First, the openness of the lake area meant that the maximum SWE on the lake surface was most likely considerably less than the maximum SWE calculated in more sheltered land areas. Second, melt rate was affected by the length of the melt period, which is naturally longer the more snow is present, but which was not accounted for in the error estimation. Averaging bountiful snow years with the general melt period length naturally gives higher melt rates compared to true situation.

In the estimation of surface runoff there existed a possible error source from the difference of assumed covered surface runoff area A_{gauged} and the actual surface runoff area where the measured surface runoff occurs (FiguresFigure 2.1 and Figure 3.3). This was due to the difference in the place from where the sub-catchment areas were computed, which for the sake of uniformity was assigned as the point where the streams meet Lake Pesiöjärvi, and the actual location of the discharge measurements, which was most likely closer towards the outflow point of the upstream lakes. Therefore the surface runoff that was generated along the stream was missing from the calculation. The sub-catchments most affected by this were Pieni-Pesiöjärvi and Itäjärvi catchments. However, considering the difference of catchment areas of Pieni-Pesiöjärvi calculated from the stream connection point to Lake Pesiöjärvi and the Lake Pieni-Pesiöjärvi outlet and re-computing the daily surface runoff, it was estimated, that the magnitude of the error to the water budget was less than 1 % of Q_{netin}.

Another error was present in the definition of runoff, which was assumed to include groundwater flow to the upstream water bodies. This means that the runoff from land areas adjacent to Lake Pesiöjärvi also included groundwater flow, which affects the final calculated groundwater flow values. However, considering the relatively small size of the lake adjacent land areas compared to the whole catchment, this error was thought to be negligible.

In order to improve the precision of the water budget and decrease the sensitivity to especially evaporation, chemical budget with a tracer analysis could be added alongside it (Rosenberry et al. 2015). When all the fluxes are known, comparing the concentration of some conservative chemical constituent (e.g. chlorine) in the different fluxes it is possible to determine the volume of groundwater flow to lake. However, inclusion of chemical budget would complicate the analysis, since the constituent concentration might vary intra-annually and between locations.

5 Conclusions

In this thesis trends in climate, hydrology and hydrochemistry in Lake Pesiöjärvi and its catchment were analysed. In conjunction with the trend analysis, a land cover and use analysis was made. In water budget analysis the role of groundwater inflow in the net inflow of Lake Pesiöjärvi was inspected, along with its sensitivity to the estimated evaporation.

Trend analysis was executed with the Mann-Kendall trend and Sen's slope tests. It revealed positive trends in January, February and March MQs and spring and annual NQ time series in 1980-2017. In addition, precipitation and air temperature exhibited positive trends in early winter, while annual max SWE showed a decreasing trend. Lake ice was also retreating earlier in the year. For total nitrogen, especially the smaller upstream lake Lake Pieni-Pesiöjärvi showed positive trends in both surface and lake floor in winter and decreasing trend in spring for lake surface. Lake Pesiöjärvi showed possible positive trends for lake floor in spring and lake surface in summer. The results of the trend analysis agree in most parts well with previous research done in Finland and in Nordic and European scale and demonstrate the influence of climate variability on hydrology and hydrochemistry.

Land use analysis was conducted by comparing the land cover and use information available from the observation period of 1980-2017. The amounts of forested, agricultural and urban areas stayed approximately steady. The prevailing land cover types were boreal forest on mineral soil and peatland forest. During the observation period peatland drainage was the major transformer of land. The share of drained peatland increased from 60 to 75 % of total peatland forest. 0-9 km^2 or 0-8 % of the catchment area changed from forested peatland to forest in mixed or mineral soil due to peatland drainage. The large spread in the result was due to contradictions in the definitions of land cover types. Because of the relatively small change in catchment area, an assumption was made that land use did not influence catchment hydrology and therefore all the observed hydrological trends were attributed to climate variability. However, nitrogen leaching due to peatland drainage and ditch network maintenance were a possible factor in hydrochemical trends.

Lake Pesiöjärvi water budget was studied in daily interval for suitable time periods in 1990s and early 2000s and an annual cycle of monthly mean groundwater inflow to the lake was calculated. Surface runoff component was calculated from upstream subcatchment discharge measurements. Evaporation was estimated with Class A pan evaporation, which was corrected with coefficients derived with bulk aerodynamic method utilising evaporation raft measurements. The annual average of the share of groundwater inflow to lake net inflow was 25 % and the daily flow amount was 27 000 m^3/d. The lake area specific inflow rate was 2,1 mm/d. Of the water budget components, groundwater inflow had least annual variation. The changes in groundwater inflow to lake were governed by groundwater table elevation, lake water level and surface runoff. The results of groundwater inflow compared well with previous research and showed that it is possible to inspect the role of groundwater in lake water budget with relatively simple measurement procedures. Although the result is only an estimate with some rough assumptions, as an estimate it is easily scalable for similar land cover and lake percent catchments.

The usability of the bulk aerodynamic method in the correction of Class A pan evaporation values as well as the sensitivity of the water budget analysis to evaporation was also studied. The evaporation coefficients calculated with bulk aerodynamic method resulted in generally higher evaporation estimates compared to previous studies and the hydrological model of SYKE. However, the shape of the evaporation curve over summer was similar to the compared sources. The different evaporation estimates used did not have a great influence in the annual averages of water budget components, but significantly influenced the monthly average values in summer and even altered the shape of the annual cycle curve of GW inflow and the timing of the maximum and minimum values. This showed that if the goal of a water budget study is in the intra-annual dynamics of the components, it is important to consider the estimation of evaporation.

The main challenges in the Pesiöjärvi data were due to variation in the quality of the data available. Some observation time series (e.g. discharge, groundwater, evaporation) were complete since their start while some (e.g. water quality sampling, snow water equivalent) had unexplainable gaps in the series. However, especially in the perspective of water budget and groundwater – surface water interaction the Pesiöjärvi catchment provides a promising research area. Because of the already existing four groundwater stations around Lake Pesiöjärvi, the further study of the groundwater – lake interaction would be possible with only small investments in equipment. For instance, the general precision of the groundwater-lake interaction could be improved by adding groundwater flow measurements or chemical budget and tracer analyses alongside the water budget analysis. In addition, by conducting new measurement of surface runoff, it would be possible to inspect the impact of climate variability in the lake water budget and groundwater – surface water interaction. Another promising study area in Pesiöjärvi catchment would be the trend analysis of different nitrogen fractions within the catchment.

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Appendices

Appendix 1 Area and volume profile of Lake Pesiöjärvi by depth

Table 1 The area and volume of Lake Pesiöjärvi in varying depth.

Depth m	Area ha	Volume 10^3 m^3
0	1274,06	50157,98
1	936,11	39370,94
2	795,87	30846,54
3	693,72	23377,62
4	544,72	17216,25
5	429,12	12362,98
6	323,33	8593,51
7	240,7	5835,94
8	191,09	3693,15
9	151,51	1985,64
10	93,16	702,57
11	26,12	176
12	5,76	41,35
13	1,48	7,85
14	0,21	1,16
15	0,04	0,1

Appendix 2 Results of the trend analysis

This appendix displays the results of the trend analysis of some of the hydrological and hydrochmenical quantities monitored in Pesiöjärvi catchment and the indices derived from them.

The significance of the trend has been interpreted according to Table 3.2 and the significance has been presented in the following tables as follows: a statistically significant trend is in **bold**, likely significant trend is in normal and possible trend is in *cursive* font style.

Table 1 displays the trend analysis results for annual MQ, HQ and NQ, value and timing of spring HQ and spring and autumn NQ. The NQ time series have been splitted in several parts due to possible heterogeneities caused by renovation of Lake Pesiöjärvi discharge point in 2011 and break point indications of Pettitt's test.

Table 2 displays the trend analysis results for the winter and spring months that showed significant monthly MQ trends over period 1980-2017. For the monthly MQ values similar splitting of time series have been done in 2011 and Pettitt's test break points as for NQ.

Table 3 displays trend analysis results for the climatic and hydrological quantities apart from discharge.

Table 4 displays the trend analysis results for total nitrogen concentration in Lake Pesiöjärvi and Lake Pieni-Pesiöjärvi.

Table 1 Trend analysis results for annual MQ, HQ and NQ, value and timing of spring HQ and spring and autumn NQ.

Quantity			Trend				Homogeneity		Notes
Quantity	**Indice**	**Time period**	**Time / type**	**Trend**	**p-value**	**Trend/year**	**p-value**	**Change point**	
Discharge	Annual MQ	1980-2017	MQ	-					
	Winter MQ	1980-2017	Winter	**Positive**	**p < 0,01**	**1,49 %**	p < 0,01	2003	
	Winter MQ	1980-2002	Winter	Positive	p < 0,07	1,47 %			
	Winter MQ	2003-2017	Winter						
	Spring MQ	1980-2017	Spring	-					
	Summer MQ	1980-2017	Summer	-					
	Autumn MQ	1980-2017	Autumn	-					
	Annual HQ	1980-2017	HQ	-					
	Spring HQ	1980-2017	HQ	-					
	Spring HQ timing	1980-2017	HQ	-					
	Annual NQ	**1980-2017**	**NQ**	**Positive**	**p < 0,01**	**2,92 %**	p < 0,04	2005	
	Annual NQ	*1980-2005*	*NQ*	*Positive*	*p = 0,13*	*0,89 %*			
	Annual NQ	*2006-2017*	*NQ*	*Positive*	*p = 0,10*	*5,27 %*			
	Annual NQ	**1980-2010**	**NQ**	**Positive**	**p < 0,05**	**0,96 %**			
	Annual NQ	2011-2017	NQ	Positive	p < 0,10	9,31 %			
	Spring NQ	**1980-2017**	**NQ**	**Positive**	**p < 0,01**	**1,38 %**	p < 0,03	1988	Significant serial correlation
	Spring NQ	1980-1988	NQ	-					
	Spring NQ	*1989-2017*	*NQ*	*Positive*	*p = 0,16*	*0,83 %*			
	Spring NQ	**1980-2011**	**NQ**	**Positive**	**p < 0,04**	**1,02 %**	p < 0,04	1988	
	Spring NQ	2012-2017	NQ	-					
	Autumn NQ	1980-2017	NQ	-					
	Autumn NQ	1980-2010	NQ	-					

Table 2 Trend analysis results for the winter and spring months that showed significant monthly MQ trends over period 1980-2017.

Quantity			**Trend**				**Homogeneity**		**Notes**
Quantity	**Indice**	**Time series**	**Time / type**	**Trend**	**p-value**	**Trend/year**	**p-value**	**Change point**	
Discharge	**Monthly MQ**	**1980-2017**	**January**	**Positive**	**p < 0,01**	**1,48 %**	p < 0,02	2004	
	Monthly MQ	1980-2003	January	-					
	Monthly MQ	2004-2017	January	-					
	Monthly MQ	**1980-2010**	**January**	**Positive**	**p < 0,03**	**1,43 %**			
	Monthly MQ	2011-2017	January	-					
	Monthly MQ	**1980-2017**	**Febryary**	**Positive**	**p < 0,01**	**1,67 %**	p < 0,01	2004	
	Monthly MQ	*1980-2003*	*Febryary*	*Positive*	*p = 0,11*	*1,43 %*			
	Monthly MQ	2004-2017	Febryary	-					
	Monthly MQ	**1980-2010**	**Febryary**	**Positive**	**p < 0,01**	**1,63 %**	p < 0,04	1991	
	Monthly MQ	2011-2017	Febryary	-					
	Monthly MQ	**1980-2017**	**March**	**Positive**	**p < 0,01**	**1,53 %**	p < 0,02	1991	
	Monthly MQ	1980-1990	March	-					
	Monthly MQ	**1991-2017**	**March**	**Positive**	**p < 0,04**	**1,50 %**			
	Monthly MQ	**1980-2010**	**March**	**Positive**	**p < 0,01**	**1,16 %**	p < 0,02	1988	
	Monthly MQ	2011-2017	March	-					
	Monthly MQ	**1980-2017**	**April**	**Positive**	**p < 0,01**	**1,62 %**	p < 0,05	1988	Singnificant serial correlation
	Monthly MQ	1980-1987	April	-					
	Monthly MQ	*1988-2017*	*April*	*Positive*	*p = 0,16*	*1,00 %*			
	Monthly MQ	*1980-2010*	*April*	*Positive*	*p = 0,12*	*1,06 %*			
	Monthly MQ	2011-2017	*April*	*Positive*	*p = 0,13*	*16,89 %*			
	Monthly MQ	**1980-2017**	**December**	**Positive**	**p < 0,04**	**1,30 %**			
	Monthly MQ	1980-2010	December	-					
	Monthly MQ	2011-2017	December	-					

Table 3 Trend analysis results for the monitored quantities and indeces in Pesiöjärvi catchment.

Time series			Trend				Homogeneity		Notes
Quantity	**Indice**	**Time period**	**Time / type**	**Trend**	**p-value**	**Sen's slope**	**p-value**	**Change point**	
Precipitation	*Monthly mean P*	*1981-2017*	*August*	*Positive*	*p = 0,10*	1,1 %			Non-corrected and constant corrected
	Monthly mean P	*1981-2017*	*August*	*Positive*	*p = 0,11*	0,9 %			Model corrected
	Monthly mean P	*1981-2017*	*December*	*Positive*	*p = 0,10*	1,1 %			Model corrected
	Monthly mean P	**1981-2017**	**December**	**Positive**	**p = 0,04**	**1,8 %**	p < 0,03	2010	Constant corrected
	Annual mean P	1981-2017		-					
Air temperature	**Monthly mean T**	**1979-2017**	**August**	**Positive**	**p < 0,05**	0,3 %			
	Monthly mean T	**1979-2017**	**September**	**Positive**	**p < 0,05**	0,6 %			
	Monthly mean T	**1979-2017**	**November**	**Positive**	**p < 0,05**	2,4 %			
	Monthly mean T	**1979-2017**	**December**	**Positive**	**p < 0,05**	1,5 %			
	Annual mean T	**1979-2017**	**Mean T**	**Positive**	**p < 0,01**	3,4 %	p < 0,03	1990	
Water temperature	**Seasonal water surface T**	**1985-2018**	**Autumn (esp. Sept.)**	**Positive**	**p < 0,01**	1,0 %	p < 0,04	1995	Gaps in data.
SWE	Modelled max	1990-2013		-					
	Measured max	*1981-2018*		*Negative*	*p = 0,13*	-0,6 %			Gaps in data.
Groundwater	Timing of autumn max GW level	1979-2017		-					
Lake ice cover	Ice formation	1992-2017	Autumn	-					Gaps in data.
	Thaw	*1993-2018*	*Spring*	*Negative*	*p = 0,15*	-3,1 %			Gaps in data.
	Ice cover period	1993-2018		-					Gaps in data.
	Max ice thickness	1993-2019		-					Gaps in data.

Table 4 Trend analysis results for total nitrogen in the studied sample points

Sampling point		Pesiöjärvi 2				Pieni-Pesiöjärvi				Uittosalmi	
Depth	**Season**	**Time period**	**Trend**	**p-value**	**Change point**	**Time period**	**Trend**	**p-value**	**Change point**	**Time period**	**Trend**
0-2m	**Winter**	1981-2013*	No			1981-2013*	**Positive**	**p < 0,05**			-
	Spring	1987-2017*	No			1987-2017*	**Negative**	**p < 0,05**		1980-2008	No
	Summer	1987-2017	*Positive*	*p = 0,13*		1984-2017	No			1979-2008	No
	Autumn	1986-2005*	No			1986-2008	No			1982-2008	No
8- m	**Winter**	1981-2013*	No			1981-2013*	Positive	p < 0,10			-
	Spring	1987-2017	Positive	p < 0,08	2001	1987-2017	*Positive*	*p = 0,15*			-
	Summer	1987-2017	No			1984-2017	No				-
	Autumn	1986-2017	No			1986-2008*	No				-
0- m	**Winter**	1981-2013*	No			1981-2013*	**Positive**	**p < 0,05**			-
	Spring	1987-2017*	No			1987-2017*	No			1980-2008	No
	Summer	1987-2017	No			1984-2017	No			1979-2008	No
	Autumn	1986-2017	No			1986-2017*	No			1982-2008	No

Appendix 3 Tables of land cover analysis

Table 1 Description of land cover in 1980 (Postila 1981) and 2012 (SYKE 2014). The values below the dividing line are aggregates of several categories of the original data. The aggregates are defined in Table 2.

1980				2012		
Land use type according to Postila (1981)	**Area (km^2)**	**% of catchment area**		**% of catchment area**	**Area (km^2)**	**Land use type according to CLC (SYKE 2014)**
Total area	102,5				102,6	
Lakes	17,0	17 %		16 %	16,8	Water bodies
Agricultural areas	4,2	4 %	>	2 %	2,0	Agricultural areas
Built areas (urban, rural, traffic)	0,4	0 %	<	2 %	1,8	Built areas (urban, rural, traffic)
Boreal forests (Kangas)	44,8	44 %	>	42 %	43,0	Forest on mineral soil
- of which on peatland	2,2	2 %		18 %	18,6	Forest on peatland
- of which felled	2,7	2,7 %		60 %	61,6	Forest (total)
- of which harrowed	2,6	2,5 %		3 %	3,05	Transitional woodland / shrub, cc < 10%
- of which ploughed	5,9	5,7 %		6 %	6,45	Transitional woodland / shrub, cc 10-30%, on mineral soil
Spruce swamp (*korpi*)	5,1	5 %		6 %	5,73	Transitional woodland / shrub, cc 10-30%, on peatland
Pine swamp (*räme*)	25,8	25 %		15 %	15,23	All transitional woodlands / shrubs
Peatbogs	5,1	5 %	=	5 %	5,0	Peatbogs
All forested areas	75,7	74 %	=	75 %	76,9	All forested areas
All forested areas on mineral soil	42,6	42 %	<	48 %	49,5	All forested areas on mineral soil
All forested areas on peatland	33,1	32 %	>	24 %	24,4	All forested areas on peatland
Peatland area	38,2	37 %	>	29 %	29,4	Peatland area

Table 2 Definitions of the aggregates of land cover categories used in the comparison of past (Postila 1981) and present (SYKE 2014) situation.

Land cover type aggregates	1980	Present
All forested areas	Sum of boreal forest, spruce swamp and pine swamp	Sum of CLC categories 3xxx; forest and transitional woodland / shrub
All forested areas on mineral soil	Boreal forest excluding peatland forest	Sum of CLC categories 31x1 and 3242; forest and transitional woodland / shrub on mineral soil
All forested areas on peatland	Sum of peatland forest, spruce swamp and pine swamp	Sum of CLC categories 31x2 and 3243; forest and transitional woodland / shrub on peatland
Peatland area	Sum of forested area on peatland and peatbogs	

Table 3 Soil type according to Postila and GTK, as well as amount of peatland in the MTK peatland GIS-layer.

Soil type definition	Source	km2	% of catchment
Peat soil	Postila (1981)	36,0	35 %
Peat (thick and shallow layer) and swamps	GTK (2009)	29,9	29 %
Mixed soil (GTK) overlaying peatland area (CLC)	GTK (2009) & SYKE (2014)	6,6	6 %
Peat soil (GTK) overlaying non-peatland area (CLC)	GTK (2009) & SYKE (2014)	6,7	7 %
Area of peatland	MML (2017)	34,7	34 %

Appendix 4 Land cover comparison of water level gauged and non-gauged catchment area

Table 1 Land cover ratios of the covered and leftover surface runoff areas as well as for whole Pesiöjärvi catchment. The ratios have been calculated against the total area of the separate fragments of the catchment. It is noticeable that the differences in land cover ratios between the areas are in all cases within 2%. Thus the covered surface runoff area describes the whole catchment surface runoff conditions well.

	Catchment area (no lake) $A_{catchment}$	**Gauged runoff area** A_{gauged}	**Non-gauged runoff area** $A_{non\text{-}gauged}$
Area (km2)	89,9	63,2	26,7
Share of whole catchment area (excluding Lake Pesiöjärvi (%)		70 %	30 %
CLC 2012 definition			
Continuous urban fabric	0 %	0 %	
Discontinuous urban fabric	0 %	0 %	1 %
Commercial units	0 %	0 %	0 %
Industrial units	0 %	0 %	0 %
Road and rail networks and associated land	1 %	1 %	2 %
Mineral extraction sites	0 %	0 %	
Summer cottages	0 %	0 %	1 %
Sport and leisure areas	0 %	0 %	0 %
Non-irrigated arable land	2 %	1 %	3 %
Land principally occupied by agriculture, with significant areas of natural vegetation	1 %	1 %	1 %
Broad-leaved forest on mineral soil	0 %	0 %	0 %
Broad-leaved forest on peatland	0 %	0 %	0 %
Coniferous forest on mineral soil	36 %	37 %	35 %
Coniferous forest on peatland	15 %	16 %	14 %
Coniferous forest on rocky soil	0 %	0 %	0 %
Mixed forest on mineral soil	11 %	11 %	13 %
Mixed forest on peatland	5 %	5 %	6 %
Transitional woodland/shrub, cc < 10%	3 %	3 %	4 %
Transitional woodland/shrub, cc 10-30%, on mineral soil	7 %	8 %	6 %
Transitional woodland/shrub, cc 10-30%, on peatland	6 %	7 %	5 %
Transitional woodland/shrub, cc 10-30%, on rocky soil	0 %	0 %	0 %
Inland marshes, aquatic	0 %	0 %	0 %
Peatbogs	6 %	5 %	6 %
Water courses	0 %	0 %	0 %
Water bodies	5 %	5 %	4 %